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# Very Large Telescope

## Paranal Science Operations

## VISTA User Manual

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# Contents

# 1 Introduction

VISTA or **V**isible[1] and **I**nfrared **S**urvey **T**elescope for **A**stronomy is a specialized 4-m class wide field survey telescope for the Southern hemisphere. VISTA is located at ESO Cerro Paranal Observatory in Chile (longitude 70$^o$ 23' 51"W, latitude 24$^o$ 36' 57" S, elevation 2500 m above sea level) on its own peak about 1500 m N-NE from the VLT.

The telescope has an alt-azimuth mount, and quasi-Ritchey-Chretien optics with a fast f/1 primary mirror giving an f/3.25 focus at the Cassegrain focus. It is equipped with a near infrared camera (1.65 degree diameter field of view (FOV) at VISTA's nominal pixel size) containing 67 million pixels of mean size 0.339 arcsec. The instrument is connected to a Cassegrain rotator on the back of the primary mirror cell, and has a wide-field corrector lens system with three infrasil lenses. The available filters are: broad band $ZYJHK_S$ and a narrow band filter at 1.18 micron. The point spread function (PSF) of the telescope+camera system delivers images with a full width at half maximum (FWHM) of $\sim$0.51 arcsec. The weather characteristics and their statistics are similar to those for the VLT.

VISTA has one observing mode - imaging - and the telescope is used mostly in service mode to carry out surveys - programs exceeding in size and scope the usuall ESO Large Programs. Typically, the observations are carried out in a 6-step pattern, called *tile*, designed to cover the gaps between the individual detectors.

The high data rate (on average 315 GB per night) and the large size of the individual files (256.7 MB) makes it a significant challenge for an individual user to cope with the rigours of the data reduction. The VISTA raw data are available via the ESO archive. In the case of the ESO Public Surveys high-level data products are also available via the ESO archive.

This manual is divided into several sections, including a technical description of the telescope and the camera, a section devoted to the observations with VISTA, including general information about the nature of the infrared sky, the operation of VISTA, the sensitivity of the instrument and a (preliminary) calibration plan. Next, the manual summarizes the data flow, the pipeline, and the parameters that are used for the quality control. Finally, the Appendix contains a template reference guide.

This manual was based on many documents, kindly provided by the VISTA consortium. The authors hope that you find it useful in your research with VISTA. The manual is continuously evolving with the maturing of the telescope and there will always be room for improvement. Comments from the users are especially welcomed. Please, refer to the ESO VISTA web site for contact details.

**Nota Bene:**

- The web page dedicated to VISTA is accessible from the La Silla Paranal Observatory home page at: `http://www.eso.org/sci/facilities/paranal/instruments/vista/`
  You will find there the most up-to-date information about VISTA, including recent news, efficiency measurements and other useful data that do not easily fit into this manual or is a subject of frequent changes. This web page is updated regularly.

  An external (with respect to ESO) source with history of the project and relevant information is

[1] A wide field visible camera was considered during the early stages of VISTA development, accounting for the visible component to the telescope name.

the VISTA consortium web-page at: `http://www.vista.ac.uk/index.html`

- Please, read the User Manual!

## 2 Applicable documents

TBA

# 3 Abbreviations and Acronyms

The abbreviations and acronyms used in this manual are described in Table 1.

Table 1: Abbreviations and Acronyms used in this manual.

| | | | |
|---|---|---|---|
| ADU | Amalog-Digital Units | MINDIT | Minimum DIT |
| AG | Autoguider | NDIT | Number of DITs |
| BOB | Broker of Observing Blocks | NDR | Non-Destructive Read |
| CDS | Correlated Double Sample | NINT | Number of NDITs |
| | (IR detector readout mode) | NTT | New Technology Telescope |
| CP | Cryo-pump | OB | Observing Blocks |
| DFS | Data Flow System | OS | Observing Software |
| DAS | Detector Acquisition System | OT | Observing Tool |
| DCR | Double Correlated Read | P2PP | Phase 2 Proposal Preparation |
| DCS | Detector Control System | PDU | Power Drive Unit |
| DEC | Declination | PSF | Point Spread Function |
| DIT | Detector Integration Time | RA | Right Ascension |
| ESO | European Southern Observatory | QC | Quality Control |
| ETC | Exposure Time Calculator | RON | Read Out Noise |
| FCA | Force Control Assembly | SADT | Survy Area Definition Tool |
| FITS | Flexible-Image Transport System | SM | Service Mode |
| FOV | Field Of View | SOFI | Son Of ISAAC |
| FPA | Focal Plane Assembly | TBC | To Be Confirmed |
| FWHM | Full Width at Half Maximum | TCS | Telescope Control System |
| GFRP | Glass Fibre Reinforced Plastic | TSF | Template Signature File |
| HOWFS | High Order Wave Front (curvature) Sensor | UKIRT | United Kingdom Infrared Telescope |
| ICRS | International Celestial Reference System | VDFS | VISTA Data Flow System |
| ICS | Instrument Control System | VIRCAM | VISTA InfraRed Camera |
| IR | Infra-Red | VLT | Very Large Telescope |
| ISAAC | IR Spectrograph And Array Camera | VM | Visitor Mode |
| LOCS | Low Order Curvature Sensors | VST | VLT Survey Telescope |
| LOWFS | Low Order Wave Front (curvature) Sensor | VPO | VISTA Project Office |
| LCU | Local Control Unit | WCS | World-Coordinate System |
| M1 | Primary Mirror | WFCAM | Wide-Field Camera (IR camera at UKIRT) |
| M2 | Secondary Mirror | ZP | Zero Point |
| MAD | Median of Absolute Deviation | ZPN | Zenithal PolyNomial (Projection) |

# 4 VISTA the telescope – Technical Description

VISTA is a 4-m class wide field survey telescope (Figure 1). It has an alt-azimuth mount, and quasi-Ritchie-Chretien optics with a 4.10-m fast f/1 primary mirror (M1) giving an f/3.25 focus at the Cassegrain. The f/3 hyperboloid-shaped secondary (M2) has a diameter of 1.24-m. The unvignetted field of view is 2 degr (but VIRCAM uses only $\sim$1.6 degr). The entrance pupil has a diameter of 3.70-m. The focal length is 12.072-m. The mirrors are coated with silver, which is optimal for near-infrared performance.

The total telescope mass (above the foundation peer) is $\sim$113 metric tons, distributed among the optical support structure ($\sim$44), the azimuth rotation structure ($\sim$46) and the pedestal assembly ($\sim$23). The primary mirror weights 5520 kg, the VIRCAM – 2900 kg, the secondary mirror – 1000 kg.

The telescope has three Power Drive Units (PDU) enabling movement of the azimuth and altitude axis, and the Cassegrain rotator. Unlike most other telescopes, VISTA lies on a ball bearing with a pitch diameter of 3658 mm, instead on a oil bed.

The Altitude limit is $\geq$20 degr above the horizon, which implies a *mechanical* pointing limit to the North at $\delta\leq$+45 degr at the meridian.

VISTA is subject to the same earthquake operaton and recovery constraints as the other ESO telescopes: earthquakes with Mercalli intensity up to 3 are ignored. Stronger earthquakes interrupt the observations and require various degrees of checking, recovery, and/or alignment procedures.

The VISTA theoretical pointing error over the entire sky is 0.5 arcsec. The open-loop tracking error over 5 min of observation is 0.22-0.24 arcsec. The telescope can operate under humidity of up to 80%. when the temperature is within the operational temperature range of T=0–15 C. VISTA can not observe within 2 degr from the zenith because of a rotator speed limitation.

The “jitter” movements are accomplished by moving the entire telescope (unlike the UKIRT for example, where this can be done via the tip-tilt mechanism of the secondary mirror). The overheads due to moving the telescope are minimal, i.e. $\sim$2 sec for 10 arcsec jitter.

The optical layout of the telescope is shown in Figure 2. The telescope and the instrument should be treated as one integral design, i.e. the telescope is just foreoptics to the VIRCAM. The design is intertwined to the point that the telescope guider is part of the camera, i.e. it is within the camera dewar.

The primary mirror is manufactured from zerodur. Axial support is provided by 81 Force Control Assemblies (FCAs), mounted on the M1 cell, lateral support is carried out by four FCAs. The M2 position is controlled in 5 axis by a precision hexapod.

VIRCAM is connected to the telescope via rotator on the back of the primary mirror cell, and has a wide-field corrector lens system with three infrasil lenses. The camera is described in the next section.

The enclosure rotates at nominal speed of 2 deg per second and is able to stop rotation within 5 sec. It can survive wind speed of up to 36 m s$^{-1}$ **closed**. The nominal wind speed observing restrictions are: closing the dome at $\geq$18 m s$^{-1}$ and observing at least 90 degr away from the wind direction for $\geq$12 m s$^{-1}$.

The mirror coating is a major operation requiring dismounting of VIRCAM and the mirrors, and it implies interrupting the telescope operations for $\sim$10 days.

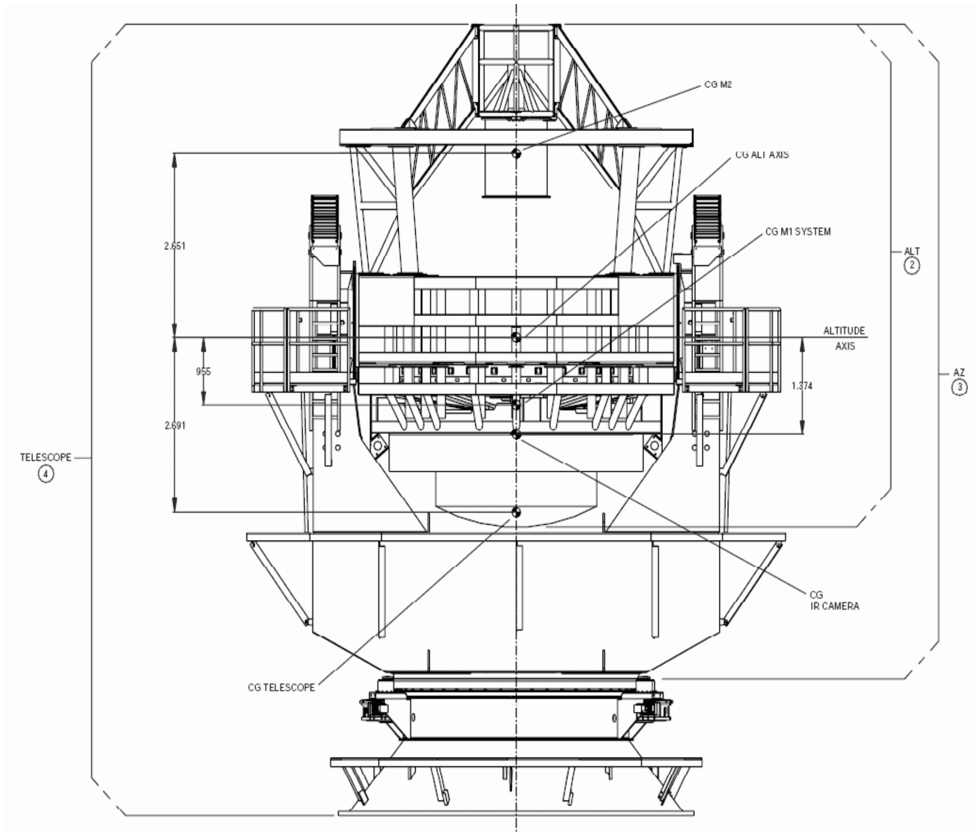


Figure 1: VISTA general view.

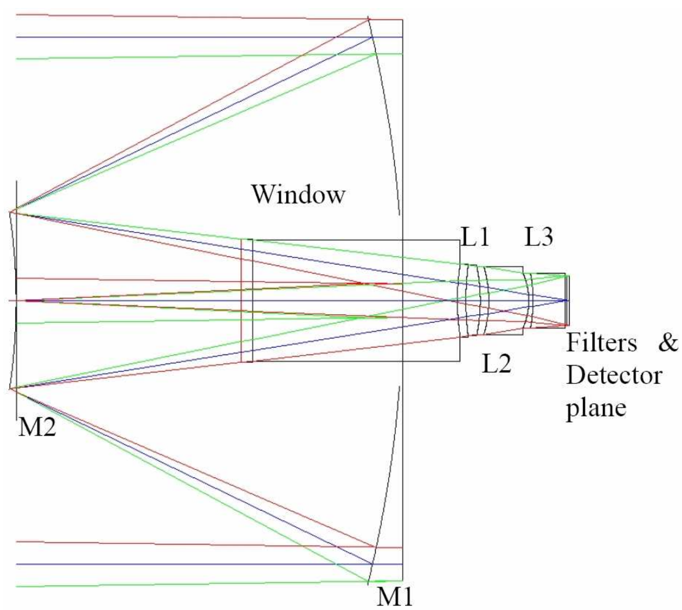


Figure 2: Optical layout of the telescope. M1 and M2 and the telescope primary and secondary mirrors. The camera's entrance window, the three lenses L1, L2, and L3, the filter and the detector planes are also marked.

# 5 VISTA Infra-Red Camera (VIRCAM)

## 5.1 General features

The infrared camera VIRCAM (Figure 3) is a state-of-the art design, the largest of the kind, as of 2008. It has a very wide available field of view with 1.65 degr diameter. The camera uses a long cryostat with seven nested cold baffles to block out-of-beam radiation instead of the usual re-imaging optics or cold pupil stop design that has been most common so far. In addition, the baffles serve to reject the unwanted heat load from the window by means of a specialized coating which is highly absorbing at wavelengths shortward of 3 $\mu$m and highly reflective longward of 3 $\mu$m.

The baffling system still leaves a smooth gradient caused by scattered thermal radiation across the detectors in the $K_S$ band; the total intensity of this scattered background is expected to be $\sim$20% of sky and the gradient may be up to 10% of that, i.e. $\sim$2% of total sky level, including the "real" sky emission and the scattered light. This effect must be addressed during the data processing. On the positive side, the absence of a cold stop means that there is no intermediate focus, so there should be no issue with "nearly in focus" warm dust particles.

The Cassegrain rotator has a full-range of 540 degr so that the position angle of the focal plane with respect to the sky may be chosen freely. The autoguiders are fully 180-deg symmetric, so if desired one can observe a field at two camera angles 180 degr apart while re-using the same guide star and LOWFS stars.

The camera faces forward, towards the secondary mirror. The light, after bouncing off the primary and the secondary, enters the instrument through a 95 cm diameter entrance window, and then it passes through three corrector lenses (all made of IR-grade fused silica), and the filter wheel, to reach the 16 detectors assembly at the focal plane. The lenses remove the field curvature to allow a large planar array of detectors to be used, while controlling the off-axis aberrations and chromatic effects. The optical layout of the telescope+camera system is shown in Figure 2, and a camera cut off is shown in Figures 3 and 4.

Two fixed autoguiders and active optics wave-front sensors are integral part of the camera. They use CCDs operating at $\sim$800 nm (roughly I-band), to control the telescope tracking and to achieve active optics control in the telescope, to correct the flexure and other opto-mechanical effects arising from both the telescope and camera parts of the system. There are two LOWFS, a HOWFS, and the light reaches them via corresponding beamsplitters to provide two out-of-focus images, used in the analysis.

The VIRCAM field distortion can be noticeable: it is expected that the difference between the pixel scale averaged over the entire field of view and the on-axis pixel scale may reach 0.85%, with up to three times larger radial variations. Therefore, pixels can be combined without re-binning only for small jitters, up to $\sim$10 px. However, in most cases the sky background removal will dictate the usage of larger jitters, and the data reduction will require re-binning of pixels when coadding frames at different jitter positions.

The aluminum cryostat housing the camera consists of four main sections, and includes over 10-m of O-ring seals. The nominal vacuum level is $10^{-6}$ milibar, and it is achieved in two stages: an initial roughing pump-down with an external pump followed by pumping with a pair of He closed cycle cryopumps.

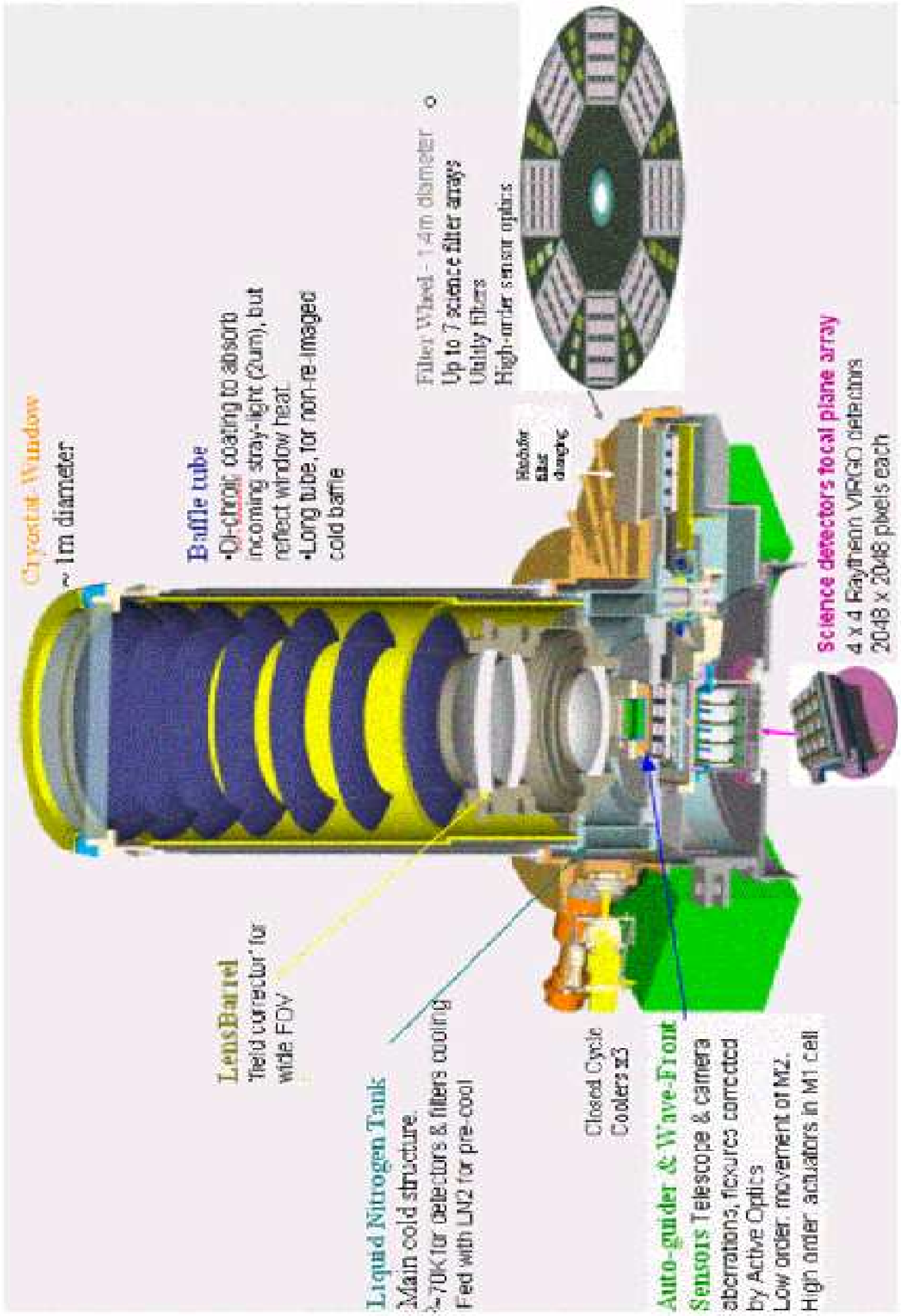


Figure 3: VIRCAM general view.

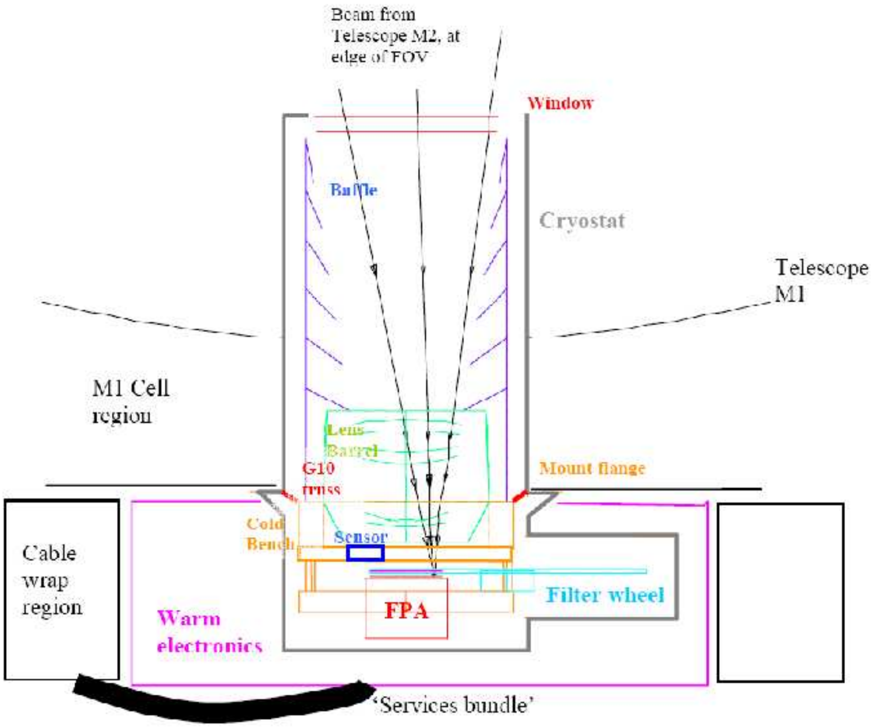


Figure 4: VIRCAM optical layout.

During normal operation the camera is maintained at temperature T∼72 K. The immediate camera cooling is achieved circulating liquid nitrogen. The total camera cooldown time is 3 days.

The IR Camera is designed with the intent that it will remain in continuous operation at cryogenic temperatures for a full year on the telescope, with a minimum annual downtime scheduled for preventative maintenance and any filter changes – baring any failures that might require emergency intervention.

## 5.2 Detectors

VIRCAM contains 16 Raytheon VIRGO 2048 px×2048 px HgCdTe science detectors (64 megapixels in total), covering 0.59 deg$^2$ per single pointing, called a **pawprint** (i.e. taken without moving the telescope). The spacing between the arrays is 90% or 42.5% of the detector size, along the X and Y axis, respectively (Figure 5). Therefore, a single pointing provides only a partial coverage of the field of view. A complete, contiguous coverage of the entire 1.5×1 degr field of view can be obtained with a six-point observing sequence, called a **tile**. For more details on the tile and achieving a full contiguous coverage see Section 6.3

The telescope+camera optics together produce a on-axis plate scale on the camera focal plane of 17.0887 arcsec mm$^{-1}$, with a focal length of 12.07 m. Each detector pixel size is 20 $\mu$m, and the 2048×2048 pixel detectors cover an area of 40.96 mm×40.96 mm on the focal plane. The pincushion distortion (due to projection effects between the spherical sky and flat focal plane, and due to residual distortions in the optical system) causes the detectors further from the optical axis to cover a smaller area on the sky. The mean pixel size across the entire focal plane is 0.339 arcsec px$^{-1}$ on the sky, and each detector covers a ∼694×694 arcsec$^2$ area of sky. The 16 detectors cover 274.432 mm×216.064 mm on the focal plane, which gives a nominal field of view of 1.292×1.017 degr on the sky. To ensure the flatness of the focal plane assembly (FPA), all pixels are

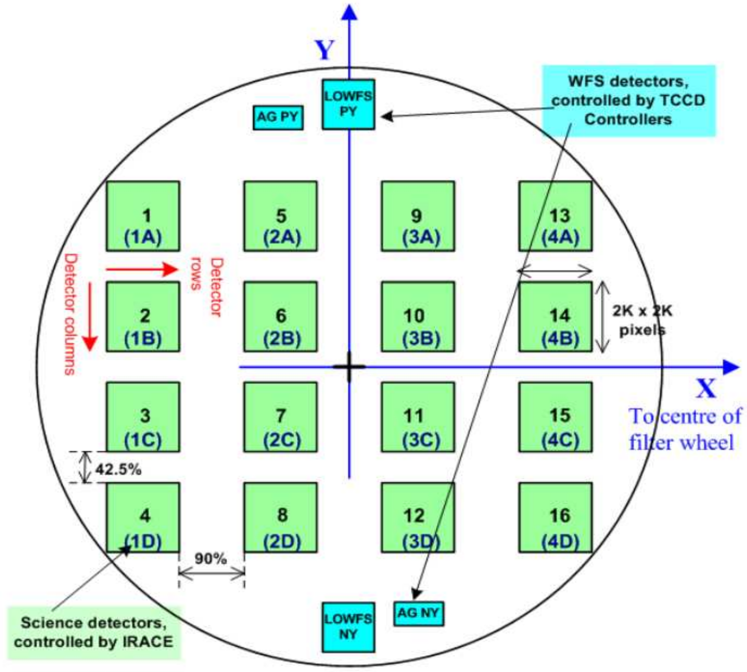


Figure 5: VIRCAM detector plane. The numbers in brackets at each science detector indicate the number of the IRACE controller used to run the corresponding detector. The wavefront sensors are also shown. The gaps between the detectors are ∼10.4 and ∼4.9 arcmin, along the X and Y axis, respectively. Each detector covers ∼11.6×11.6 arcmin on the sky. North is up, and East is to the right, for rotator offset 0.0.

located between two planes, separated by 25 $\mu$m, measured along the optical axis of the camera.

The Nyquist sampling suggests image quality of ∼0.68 arcsec but it is expected to gain a factor of ∼0.7 in resolution because of the sub-pixel sampling. The science detectors are sensitive over wavelength range from 0.85 to 2.4 $\mu$m. The detector readout time is ∼1 sec and the size of a single file is ∼256.7 MB.

The mean quantum efficiencies of all 16 detectors are: ($Z$,$Y$,$J$,$H$,$K_S$)=(70,80,90,96,92)%. A plot of the quantum efficiency as function of wavelenght for this type of the detectors in shown in Figure 6. In addition, the combined losses due to reflection off all VIRCAM lens surfaces are 3-5%.

The science detectors are read out simultaneously by four enhanced ESO IRACE IR controllers, with a total of 256 simultaneous readout channels, so each detector is read into 16 stripes of 2048×128 pixels.

All detectors but one are linear to ≤3.3% for illumination levels bellow 10000 ADU, and for the worst one the non-linearity at this level is ∼6%. The most recent studies place it to 2.2-12.4%, depending on the detector. These values may change with time, check the VIRCAM web page for more up to date information. The linearity is correctable for up to ∼25000 ADU (the number varies for the different detectors). The stability of the non-linearity corrections will be studied and reported later. Well-depths for the arrays (defined as the point at which the non-linearity of the response exceeds 5%) range between 110000 and 180000 $e^-$, for a bias voltage set at 0.7 V. For an average gain of ∼4.3 $e^-$ $ADU^{-1}$, these correspond to ∼26000 and 42000 ADU.

The minimum detector integration time is 1.0011 sec and with this DIT, under seeing of 0.6 arcsec, near the zenith (sec $z$∼1.05), the peak values in the images of stars with $Z$∼11.3, $Y$∼10.8, $J$∼11.1, $H$∼11.0, and $K_S$∼10.2 mag reach ∼30000 ADU, i.e. the border of the uncorrectable non-linearity. The corresponding average background counts are: 41, 64, 254, 1376, and 1925, for each of the five

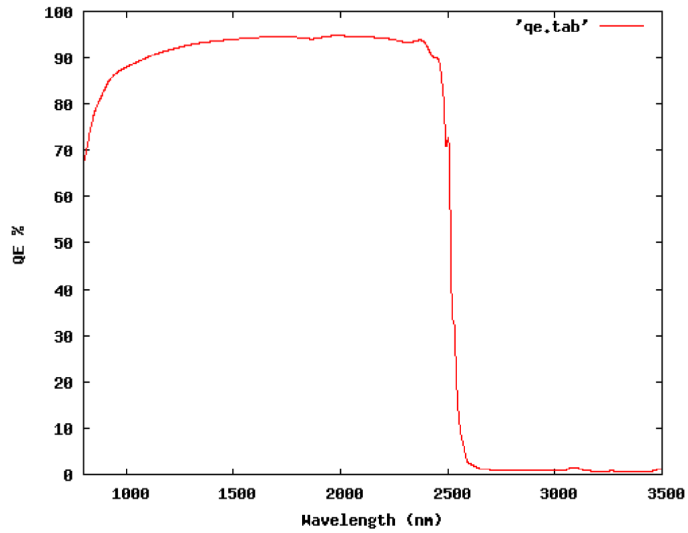


Figure 6: Quantum efficiency of the VIRCAM detectors.

broad band filters, respectively. Here, the assumed dark sky brightness is: $Z$=18.2, $Y$=17.2, $J$=16.0, $H$=14.1, and $K_S$=13.0 mag arcsec$^{-2}$. The sky alone would saturate the detector for DIT$\sim$1207, 787, 197, 36, 26 sec, for each of these bands, respectively. These values may change with time, check the VIRCAM web page for more up to date information.

The parameters of individual detectors are summarized in Table 2 for standard readout mode. Cosmetically, the best detectors are No. 5 and 10, and the worst are No. 1, 2 and 3.

The flat fielding is exceptionally stable - after the flat fielding correction the images show r.m.s. of 0.004-0.005 which promisses photometry of nearly milimag quality, taking into account that the stellar images will spread over 4-9 pixels on an individual exposure, and that the jittering and the microstepping will allow averaging over even more pixels.

### 5.3 Filters

The filter exchange wheel (1.37-m diameter) is the single moving part of the camera. It has eight main slots – seven for science filters and one for a dark. The science filter positions actually contain “trays” – each with a 4×4 array of square glass filters designed to match the 4×4 array of science detectors. The available science filters are listed in Table 3 and their parameters are given in Table 4. The filter transmission curves are plotted in Figure 7.

The wheel is driven with a step motor and it is positioned by counting the number of motor steps from a reference switch. Approximate feedback, within several hundred steps, is provided by in-position switches which are “activated” whenever the tray of science filters corresponding to the given switch is positioned in the beam.

Filter exchange time is expected to be $\sim$15-45 sec depending on required rotation angle; this is clearly longer than that for a jitter or tiling telescope move, so it is generally more efficient (and gives better sky subtraction) to complete a tile in one filter, then change filter and repeat the tile. A full wheel revolution corresponds to 210000 half-steps of the step motor, and requires $\sim$53 seconds at maximum speed.

A filter change is likely to cause a small warming of the detectors, because of the non-uniform temperature across the wheel. This effect is corrected by the temperature servo system, so the temperature rise should be $<$0.1 K for a few minutes after the change. With a wheel temperature $<$110 K, photon emission from the wheel itself should always be negligible.

Table 2: Properties of the VIRCAM science detectors. The different types of bad pixels are measured by different pipeline recipes and the adopted definitions slightly vary, hence the inconsistency. The most recent estimates put the bad pixel fraction from 0.6 to 6.9%. The last two lines give the average values and their r.m.s., over all 16 detectors.

| Detector No. | Gain $e^- ADU^{-1}$ | Readnoise $e^-$ | Dark current $ADU\,sec^{-1}\,px^{-1}$ | Hot pixels fraction, % | Bad pixels fracion, % | Non-linearity deviation at 10000 ADU, % |
|---|---|---|---|---|---|---|
| 1 | 3.6 | 22.0 | 0.64 | 0.45 | 1.93 | 1.30±0.09 |
| 2 | 4.2 | 21.4 | 0.04 | 0.51 | 1.30 | 2.09±0.11 |
| 3 | 3.9 | 21.2 | 0.43 | 0.93 | 0.91 | 2.60±0.42 |
| 4 | 4.2 | 24.3 | 0.27 | 0.45 | 0.63 | 2.14±0.18 |
| 5 | 4.2 | 22.7 | 0.05 | 0.32 | 0.14 | 1.87±0.11 |
| 6 | 4.1 | 20.4 | 0.21 | 0.33 | 0.23 | 1.69±0.07 |
| 7 | 3.9 | 22.8 | 0.21 | 0.38 | 0.22 | 1.32±0.05 |
| 8 | 4.3 | 29.3 | 1.56 | 0.34 | 0.32 | 2.23±0.24 |
| 9 | 4.6 | 21.7 | 0.18 | 0.35 | 0.27 | 2.12±0.11 |
| 10 | 4.0 | 24.5 | 0.02 | 0.33 | 0.10 | 1.75±0.06 |
| 11 | 4.6 | 27.5 | 0.23 | 0.35 | 0.24 | 3.26±0.52 |
| 12 | 4.0 | 25.8 | 0.42 | 0.38 | 0.22 | 1.61±0.05 |
| 13 | 5.7 | 30.8 | 0.79 | 0.94 | 0.90 | 5.98±0.34 |
| 14 | 4.8 | 26.5 | 1.12 | 0.61 | 0.97 | 2.04±0.03 |
| 15 | 4.0 | 19.9 | 0.13 | 0.32 | 0.53 | 1.60±0.02 |
| 16 | 5.0 | 24.0 | 1.13 | 0.27 | 1.43 | 2.45±0.11 |
| **Average** | **4.3** | **24.0** | **0.46** | **0.45** | **0.65** | **2.25** |
| r.m.s. | 0.5 | 3.2 | 0.46 | 0.21 | 0.54 | 1.11 |

Table 3: Location of the VIRCAM filters in the filter wheel slots. “INT 3” is the intermediate slot No. 3. Another narrow band filter will replace in the near future on of the darks.

| Slot | Filter |
|---|---|
| 1 | SUNBLIND |
| 2 | NB 1.18 |
| 3 | $J$ |
| INT 3 | HOWFS $J$ beam splitter |
| 4 | $K_S$ |
| 5 | $H$ |
| 6 | $Z$ |
| 7 | $Y$ |
| 8 | DARK1 |

Table 4: Paramaters of the VIRCAM filters.

| Band | $Z$ | $Y$ | $J$ | $H$ | $K_S$ | NB 1.18 |
|---|---|---|---|---|---|---|
| Nominal Central Wavelength ($\mu$m) | 0.88 | 1.02 | 1.25 | 1.65 | 2.15 | 1.185 |
| Nominal Bandwidth FWHM ($\mu$m) | 0.12 | 0.10 | 0.18 | 0.30 | 0.30 | 0.01 |
| Minimum Camera Throughput | ?.?? | 0.74 | 0.74 | 0.74 | 0.81 | 0.?? |

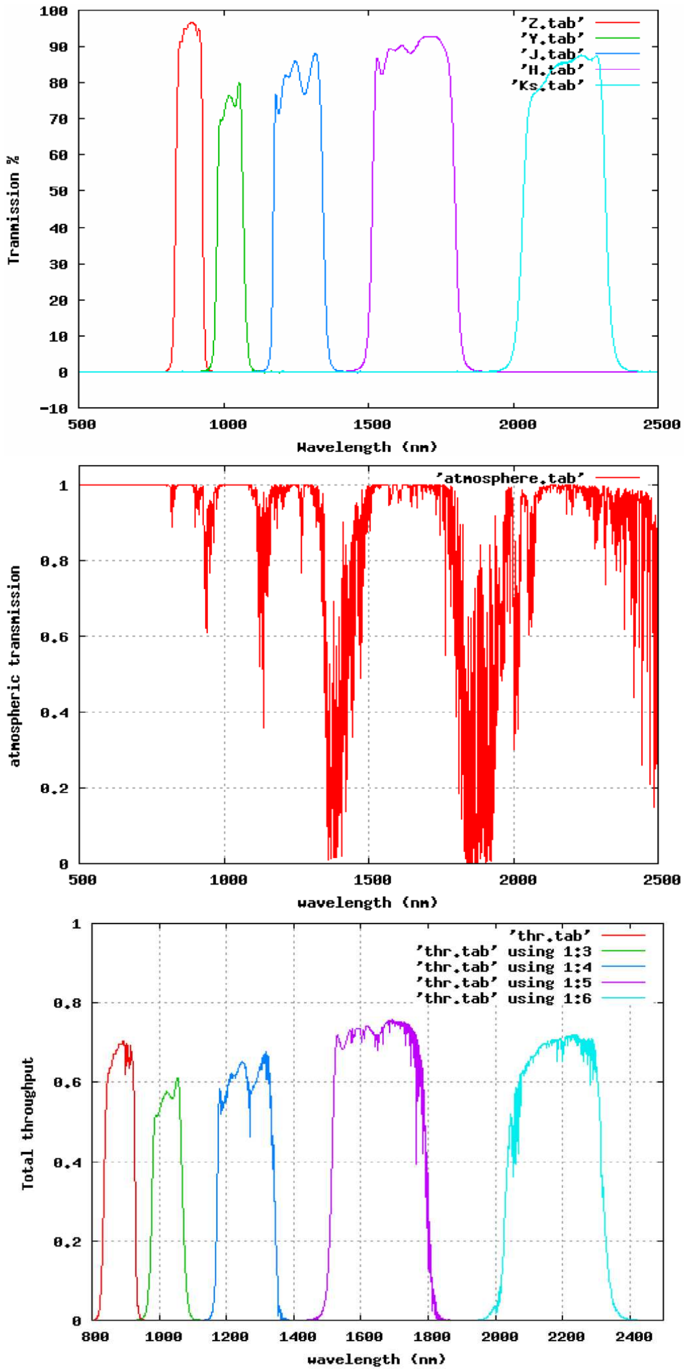


Figure 7: Transmission curves for the filters (top), for the atmosphere (middle) and for combined filters and atmosphere (bottom).

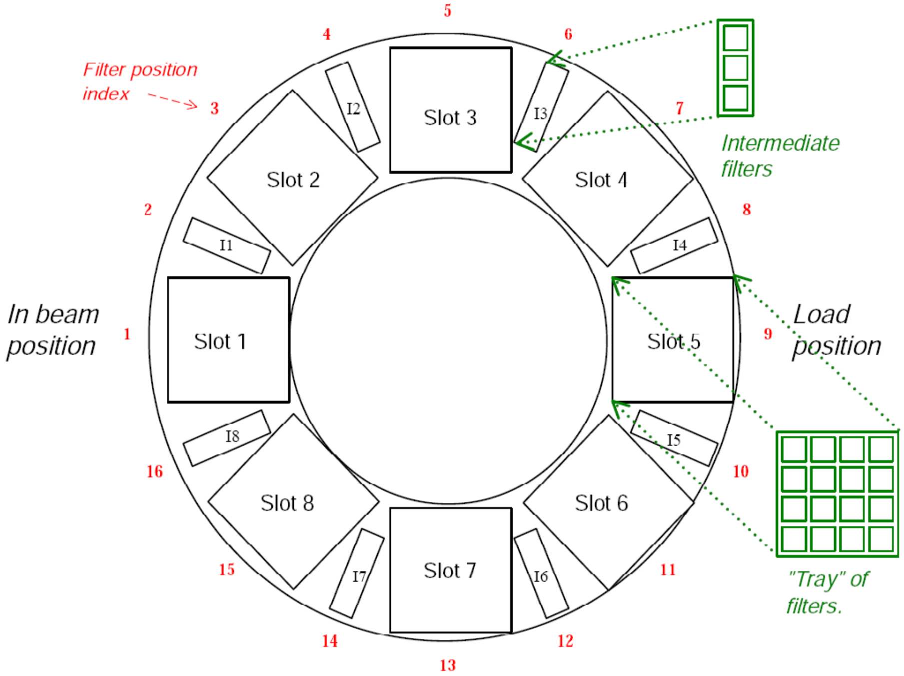


Figure 8: Layout of the VIRCAM filter wheel.

The wedge-shaped spaces in between the science filter trays can be populated with smaller "intermediate" filters that only cover a subset of the science detectors and are designed for one-off calibration observations and engineering tests. These filters can be offset from the beam center, and made to cover different detectors, by rotating the filter wheel slightly. The beam splitters for the high order wavefront sensor (HOWFS) fit into these intermediate positions.

The VISTA filter wheel control software "knows" the approximate transparency of each filter, and it is designed to protect the detectors from being flashed unnecessarily with ambient light by selecting a wheel movement path which passes the least number of "bright" filters through the beam.

## 5.4 Low Order Curvature Sensors/Autoguiders

The camera incorporates six CCD detectors grouped into two units (+Y and $-$Y) that provide auto-guiding and wavefront sensing information to the VISTA telescope control system, for the purpose of active control of the telescope optics, to correct the flexure and various opto-mechanical effects arising from both the telescope and camera parts of the system.

There are two Low Order Curvature Sensors/Autoguiders (LOCS/AGs) units – self-contained subsystems, mounted between the third camera lens and the filter wheel assembly, next to the infrared detectors (Figure 5). They can sample the beam as close as possible to the science field of view. Each unit contains three *e2v Technologies* type CCD 42-40 2048$\times$2048 CCDs with pixel scale $\sim$0.23 arcsec px$^{-1}$). The first of them uses only half of the field of view (8$\times$4 arcmin) for speed, and it provides auto-guiding capability for the telescope at up to 10 Hz frame rate for a 100$\times$100 pixel window. The other two CCDs are mounted at the two outputs of a cuboid beamsplitter arrangement which provides pre- and post-focal images for wavefront curvature analysis. They use the full field of view (8$\times$8 arcmin). From a software perspective the LOCS/AG units logically are part of the telescope control system (TCS) rather than the instrument control system (ICS).

The guide sensor operates concurrently with the science observations. It is expected that the guide sensor can start to operate within 30 min after sunset, but this may require to choose the telescope pointing placing a suitably bright guide star in the LOCS/AG field of view. The field of view of the AG units covers sufficiently large area, so there is 99% probability of finding usable guide star, for a random telescope pointing in the region of Galactic Pole at Full Moon.

The start and end of exposure on the two wavefront analysis CCDs of one sensor are coincident within 1 sec and the estimated Zernike coefficients are sent to the TCS within 15 sec from the completion of the LOCS/AG exposures. The autoguiding and the wavefront analysis add negligible overhead to the science observations – less than 0.5 sec per LOWFS frame. In other words, the LOWFS/AGs are "slaved" to the science readouts and telescope dithers to make sure the autoguiding doesn't interfere with the observations. **The use of the LOWFSs imposes a minimum time between jitter moves of $\sim$30 sec since they have to complete an exposure with adequate S/N in between consecutive jitter moves.** If it is essential to jitter more often than once per 30 sec, this can be done using open-loop M2 control - a slight loss of image quality may result.

A software enhancement may be added to enable co-adding two or more 15-sec LOWFS exposures of the same star with relative jitter shifts - this is not currently implemented but is under consideration as a software enhancement. If it is implemented, a simple co-add of LOWFS images with a shift by the nearest-integer number of pixels will be used.

There is only one case when a significant overhead from the LOWFSs may rise – after a telescope slew giving a large ($>$10 degr) change in altitude: in this case there will probably be a need for a 30 sec pause for one LOWFS cycle to be completed to update the M2 position at the new altitude, before science observing can re-start.

Given the LOWFS fields (8$\times$8 arcmin) of view, generally a "jitter" move $\sim$15 arcsec will re-use the same guide and wavefront sensor stars by simply offsetting the selected readout window in software, whereas a "tiling" move of 5-10 arcmin will almost always require different guide and LOWFS stars to be selected after the move; checking and acquiring the new guide star will add a short overhead of $\sim$1 sec per each tiling move.

There are various "graceful degradation" modes in the event of hardware failure of one sensor, unavailability of stars, etc; these include reducing the autoguider frame rate, and/or operating with one LOWFS and 3-axis M2 control.

There is no non-sidereal guiding and no closed-loop wavefront sensing during tracking of a non-sidereal target, but these features may be considered in the future.

## 5.5 High Order Wavefront Sensor Operation

The high order wavefront (curvature) sensor (HOWFS) uses some of the science detectors to determine occasional adjustments to the primary mirror support system. (This is done perhaps once at the start of the night and once around midnight.) Processing the signals from the HOWFS is done within the Instrument Workstation, and so the pipeline will not have to deal with the HOWFS related data.

HOWFS is not required to operate concurrently with science observations. The telescope can be offset to illuminate directly the sensor with a bright star, limiting the necessary FOV. The sensor within the IR Camera software package allows a suitable star to be selected. The estimates suggest that there is 99% probability of finding suitable star within 1 deg of any telescope position. The required integration time will be $\leq$180 sec, in most cases $\leq$60 sec. The HOWFS will generate at least 22 Zernike or quasi-Zernike coefficients, so that the root-sum-square error of all 22 coefficients is $\leq$50 nm. After adopting a curvature sensing solution, a "stepped" filter at one or more of the "intermediate" filter positions on the filter wheel is used to illuminate one of the science detectors in e.g. $J$ passband for verification. The HOWFS data are stored in the same manner as science exposures.

# 6 Observations with VISTA

This chapter summarizes the experience, accumulated over many years of NIR observations at the Observatory. It borrows from the similar discussions in ISAAC and SofI user manuals.

## 6.1 Observation in the Infrared

### 6.1.1 The Infrared Sky

Observing in the IR is more complex than observing in the optical. The difference arises from a higher and more variable background, and from stronger atmospheric absorption and telluric emission throughout the 1 to 2.5 micron wavelength region.

Short-ward of 2.3 microns, the background is dominated by non-thermal emission, principally by aurora, OH and $\mathrm{O}_2$ emission lines. The vibrationally excited OH lines are highly variable on a time scale of a few minutes. Pronounced diurnal variations also occur: the lines are strongest just after sunset and weakest a few hours after midnight. A complete description and atlas of the sky emission lines can be found in the paper Rousselot et al. (2000, A&A, 354, 1134).

Long-ward of 2.3 microns, the background is dominated by thermal emission from both the telescope and the sky, and it is principally a function of the temperature. The background in $K_S$ can vary by a factor of two between the winter and summer months but is more stable than the $J$ or $H$ band background on minute-long time-scale. It also depends on the cleanliness of the primary mirror. Imaging in broadband $K_S$ can result in backgrounds of up to a couple of thousand ADU sec$^{-1}$, depending strongly on the temperature and humidity.

The IR window between 1 and 2.5 microns contains many absorption features that are primarily due to water vapor and carbon dioxide in the atmosphere. These features are time varying and they depend non-linearly with airmass. The atmosphere between the $J$ and $H$ bands and between the $H$ and $K_S$ bands is almost completely opaque. The atmospheric transmittance between 0.5 and 2.5 microns is plotted in Figure 7 (middle panel). As the amount of water vapor varies so will the amount of absorption. The edges of the atmospheric windows are highly variable which is important for the stability of the photometry in $J$ and $K_S$ filters (but to a lesser extent for $J_S$).

These difficulties have led to the development of specific observing techniques for the IR. These techniques are encapsulated in the templates (see for details Appendix A) that are used to control VIRCAM and the telescope.

It is not unusual for the objects of interest to be hundreds or even thousands of times fainter than the sky. Under these conditions it has become standard practice to observe the source (together with the inevitable underlying sky) and subtract from it an estimate of the sky. Since the sky emission is generally variable, the only way to obtain good sky cancellation is to do this frequently. The frequency depends on the wavelength of observation (and respectively on the nature of the sky background emission) and on meteorological conditions. Ideally, one would like to estimate the sky more frequently than the time scale of the sky variations. While this could be done quickly with the traditional single- and especially double-channel photometers, the overhead in observing with array detectors and the necessity of integrating sufficient photons to achieve background limited performance are such that the frequency is of the order of once per minute. In exceptionally stable conditions the sky can be sampled once every two or three minutes. This sky subtraction technique has the additional advantage that it automatically removes fixed electronic patterns (sometimes called “bias”) and dark current.

**NOTA BENE:** The *sky* and the *object+sky* have to be sampled equally; integrating more on the *object+sky* than on the *sky* will not improve the overall signal-to-noise ratio because the noise will be dominated by the *sky*.

### 6.1.2 Selecting the best DIT and NDIT

Selecting the best DIT and NDIT is a complex optimization problem and it depends on the nature of the program: type of the targets, necessary signal-to-noise, frequency of sky sampling, etc. Therefore, it is hard to give general suggestions and the users should exercise their judgment and discuss their choices with the support astronomer.

The first constraint is to keep the signal from the target within the linear part of the detector array dynamic range (Table 2; for a discussion on the detector non-linearity see Sec. 5.2). At the minimum DIT of 1.0011 sec, and under seeing of 0.6 arcsec, at sec $z$∼1.05, stars of $Z$∼11.3, $Y$∼10.8, $J$∼11.1, $H$∼11.0, and $K_S$∼10.2 mag reach ∼30000 ADU at the central pixel, i.e. above the correctable (i.e. ≤5%) non-linearity.

Considering the large VIRCAM field of view, it is likely that a number of bright stars will fall into the field of view, and they will illuminate the detectors with signal well above the non-linearity limits. The data reduction pipeline is designed to correct at least partially the effects of non-linearity and cross-talk, caused by these sources. However, the requirement to keep the signal from the science target bellow the non-linearity limit is paramount.

The only way to do that is to reduce the detector integration time. Unfortunately, the smaller DIT increases greatly the overheads to ≥100%, in the cases of 1-2 sec DIT because the overhead associated with every DIT is ∼1 sec. For comparison, observations with DIT=10-20 sec have an overhead of ∼10%.

The sky background is another factor that has to be accounted for when selecting a DIT. It is the strongest in $K_S$ band when it amounts to ∼1200 ADU per second per pixel, depending strongly on the temperature and humidity. The sky background can easily saturate the array by itself if the user selects a big DIT. For the minimum DIT of 1.0011 sec, the average sky background counts are: 41, 64, 254, 1376, and 1925 ADU, for $ZYJHK_S$, respectively, for typical “dark” sky brightnesses: $Z$=18.2, $Y$=17.2, $J$=16.0, $H$=14.1, and $K_S$=13.0 mag arcsec$^{-2}$. The sky alone would saturate the detectors (at ∼50,000 ADU) for DIT∼1207, 787, 197, 36, 26 sec, for each of these bands, respectively. The exact levels achieved within this DITs will vary somewhat from one detector to another because of the different detector properties. Thin clouds and moon light can elevate the sky background significantly in $Z$, $Y$, and even in $J$.

The recommended maximum DITs for the five broad band filters are: 60, 60, 30, 10, 10 sec, respectively. These values will keep the detector potential wells less than half full minimizing problems with the saturation, persistence, non linearity, dynamic range, and not saturating the 2MASS stars (one or two magnitudes above the 2MASS limit) which are used as photometric and astrometric references. The values quoted here may change with time, check the VIRCAM web page for more up to date information.

The background variations – on a time scale of a 1-3 minutes – are a source of systematic uncertainties. To account for them the user must monitor these variations on the same time scale. As mentioned above, this is done by alternatively observing the target and a clear sky field next to the target every 1-3 minutes. The exact frequency of the sky sampling is determined by the product DIT×NDIT, plus the overhead – if the DIT value is set by the linearity constraint, the frequency of the sky samppling determiens the NDIT.

The observer can verify the choice of the sky sampling frequency by subtracting sequential images from one another and by monitoring how large is the average residual. Ideally, it should be smaller than or comparable to the expected Poisson noise but this is rarely the case. Usually, a few tens or a few hundred ADUs are considered acceptable by most users.

Finally, the total integration time is accumulated by obtaining a certain number of images, usually specified by the total number of exposures, the number of jittered images at each position, the number of microsteps, and the location of the point in the field of view (Figure 14). If relatively long integrations are necessary, it is simply a matter of increasing the number of exposures, respectively, the number of tiles. However, in the cases when the total required time can be accumulated in less than 5-7 exposures it might become difficult to create a good sky for the sky subtraction, especially if the field is crowded because the sky image may contain residuals from the stellar images that will produce “holes” in the sky-subtracted data. This situation will require to adopt a strategy with an increases number of exposures to 5 or 7. It might be possible to compensate this increase by decreasing correspondingly NDIT to keep the total integration time constant. Still, there will be some increase in the overheads. Alternatively, the sky may be constructed combining a few nearby pointings/tiles.

Summarizing, under average conditions, for faint targets, one can safely use DIT=40-60, 20-40, 5-30, 1-10 and 1-10 sec for $Z$, $Y$, $J$, $H$ and $K_S$ filters, respectively. The narrow band filters can tolerate DIT=40-120 sec. Brighter targets require to reduce these times, in some cases all the way down to the minimum DIT of 1.0011 sec for 13-18 mag stars (see above). The users may even have to consider splitting their observations into “shallow” and “deep” sequences, optimized for different magnitude ranges.

One more complication is caused by the nature of the target. If it is a point-source-like, or a sparse field of point-source-like objects, the simple dither or a tile will suffice to create a sky frame. For objects larger with respect to the field or for very crowded fields, it is necessary to image the sky and the object separately – in two different tiles – effectively adding 100% overhead. Unfortunately, it is common that the sky frames will contain other objects, and it is not uncommon that one of these objects will be in the same region of the array(s) as the science object. To avoid this it is important to jitter the sky images as well. The experience shows that a reasonable minimum number of the sky images (and respectively, the object-sky pairs) is 5-7, to ensure a good removal of the objects from the sky frames. Note that this may lead to an extra overhead because in some cases the NDIT has to be reduced artificially (contrary to the optimization strategy discussed above) to a number bellow the optimal, just to split the total integration into 5-7 images, adding an extra overhead for the telescope offsets. Considering the large field of view of VIRCAM, the user may encounter these problems only observing a handful of objects, i.e. the Galactic Center, the Magellanic Clouds.

Finally, the user should remember that the maximum total duration of an imaging OB *in Service Mode* can not exceed 1 hour. Longer OBs may be acceptable but the Observatory can not guarantee that the weather conditions will remain within the requested specification after the first hour, i.e. if the conditions deteriorate after 1 hr of observation, the OB will be completed and considered executed.

#### 6.1.3 Standard Stars

The IR window between 1 and 2.5 microns contains several large absorption features that are primarily due to water vapor and carbon dioxide in the atmosphere. The edges of the atmospheric windows are highly variable. Although the infrared filters are designed to exclude the regions affected most, for some filters, in particular $K_S$, the edges of the useful passbands are defined by these absorption features rather than the transmission curves of the filters themselves. Thus, when the column density of water vapor is variable, accurate photometry can be difficult to achieve. On good nights (generally when the humidity is low and it is cold) it has been possible to achieve better than 1% absolute photometry; however, on most nights this should be considered as the best limit and the typical accuracy is 3-5%. Of course, the relative photometry can be much more accurate. Good planing of the observations and sophisticated data reduction (i.e. image subtraction instead of aperture photometry and PSF fitting) has allowed some users to achieve on a 4-m class telescope relative photometry of a few milimagnitudes!

According to the calibration plan, about 10% of the VISTA observing time is devoted to observations of standard stars. The evening and morning twilights will be used for taking photometric calibration data as well. A network of standard star fields will be observed periodically throughout each night (approximately one every two hours). These data will enable an independent calibration to be made on a nightly basis. These touchstone fields – which will be announced in the future – will provide important information on the stability of VIRCAM, and will be used to measure any intra-detector spatial systematics. The ultimate goal is to provide photometric calibration accurate to $\sim$2%. This value may change with time, check the VIRCAM web page for more up to date information.

VISTA has an additional source of calibration, at least for some filters - the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006, AJ, 131, 1163). The 2MASS will provide the initial photometric calibration for $J$, $H$, and $K_S$. The 2MASS photometric system is globally consistent to within 1% (Nikolaev et al. 2000, AJ, 120, 3340). This approach will enable each detector image to be calibrated directly from the 2MASS stars that fall within the field of view. Experience with WFCAM indicates that this approach will result in a photometric calibration to better than 2% for VIRCAM. Note that the 2MASS base calibration can rely on a relatively narrow dynamic range because the 2MASS is relatively shallow and the photometric errors relatively large near the completeness limit. For example, at $K_S\sim$15 mag, the uncertainty is usually 0.15-0.2 mag. At the same time, the larger VISTA telescope size leads to saturation of the brighter stars, so typically, the useful magnitude range is limited to 12-14 mag in all bands.

The $Y$ and $Z$ bands have no 2MASS counterparts. However, Hodgkin et al (2009, MNRAS, 394, 675) have demonstrated that it is possible to calibrate them within the requirements of the calibration plan using the 2MASS $J$ band and the $J-H$ color as long as E($B-V$)<0.2 and E($B-V$)<1.5 mag, respectively for $Z$ and $J$.

Further details on the photometric calibration can be found in the Calibration Plan (Sec. 6.10).

## 6.2 General Operation

Nominal Operating Mode: for science observations, the camera and the telescope are driven by pre-defined OBs in the VISTA software system. The instrument is actively cooled, the IR detector system is continually taking exposures. The images are only recorded upon command triggered by an executed OB or manually via the instrument control system. In normal conditions the filter wheel moves periodically to exchange filters upon request, the AG and LOWFS sensors are continually recording images and passing data to the TCS for the active optics operation. The instrument software itself can either be in ONLINE state for normal observing and on-sky calibrations, or in STANDBY state when the instrument is left idle.

Calibration/Engineering Modes: a sub-set of the nominal mode, that covers less frequent cases, such as daytime calibrations, alignment tests, pointing models, troubleshooting. In addition, there is a “power cut mode”, designed to handle safely any disruption of the power supply.

## 6.3 Pawprints, Tiles, Offsets, Jitter

**Integration** - a simple snapshot, within the Data Acquisition System (DAS), of a specified elapsed time. This elapsed time is known also as the Detector Integration Time (DIT) and it is measured in seconds.

**Exposure** - the stored product, a sum of many individual detector integrations, that have been co-added in the DAS. Each exposure is associated with an exposure time.

**Microstep (pattern)** - a pattern of exposures (Figure 9, left) at positions each shifted by a very small movement (<3 arcsec) from the reference position. Unlike the jitter (see bellow), the fractional (i.e. non-integral) part of the shifts are specified as 0.5 pixel, which allows the pixels in the series to be interleaved in an effort to increase resolution. A microstep pattern can be contained within each position of a jitter pattern.

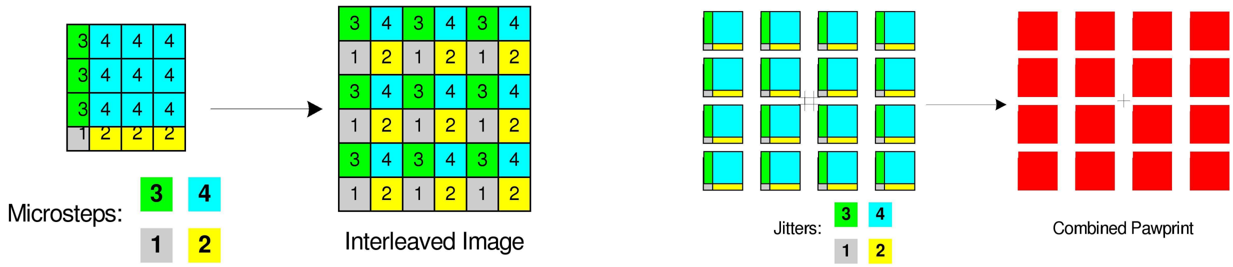


Figure 9: Combining exposures with microstepping (left) and jittering (right).

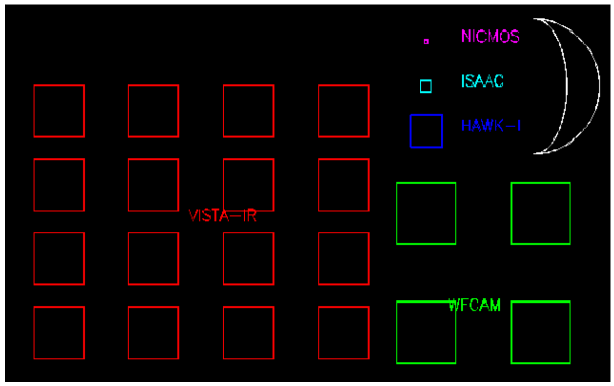


Figure 10: Comparison between the field of view of VIRCAM and other instruments.

**Jitter (pattern)** - a pattern of exposures (Figure 9, right) at positions each shifted by a small movement (<30 arcsec) from the reference position. Unlike a microstep (see above), the fractional (i.e., non-integral) part of the shifts is any fractional number of pixels. Each position of a jitter pattern can contain a microstep pattern.

**Pawprint** - the 16 non-contiguous images of the sky produced by the VISTA IR camera, with its 16 non-contiguous chips. The name is from the similarity to the prints made by the padded paw of an animal (the analogy fits earlier 4-chip cameras better).

**Tile** - a filled area of sky fully sampled (filling in the gaps in a pawprint) by combining multiple pawprints. Because of the detector spacing the minimum number of pointed observations (with fixed offsets) required for reasonably uniform coverage is 6, which would expose each piece of sky, away from the edges of the tile, to at least 2 camera pixels.

The VIRCAM focal plane is sparse, i.e. there is significant space between the detectors. Therefore, a single integration of length DIT sec (or a co-added series of these known as an Exposure; it doesn't include moving the telescope between the individual DITs) produces a sparsely sampled image of the sky known as a Pawprint (in red in the following Figures). The area of sky covered by the pixels of a pawprint is ~0.6 sq. degrees. For comparison the fields of view of NICMOS, ISAAC, HAWK-I and WFCAM are shown below in Figure 10, together with a crescent moon.

To "fill-in" the gaps between the detectors, or in other words, to produce a single **filled** Tile with reasonably uniform sky coverage, requires minimum of six pointed observations (with fixed offsets). This is achieved first by observing at three positions offset in Y (Figure 11), i.e. so that after them an area with a vertical side 5.275 detector widths (=4+3×0.425) is covered at least twice. This corresponds to 1.017 degr (61 arcmin) at VISTA's mean pixel size. There is also a strip at the top and another at the bottom which is only covered once by this tiling pattern. These strips are each 0.475 of a detector height. Each corresponding to 0.092 degr (5.5 arcmin) at VISTA's mean pixel

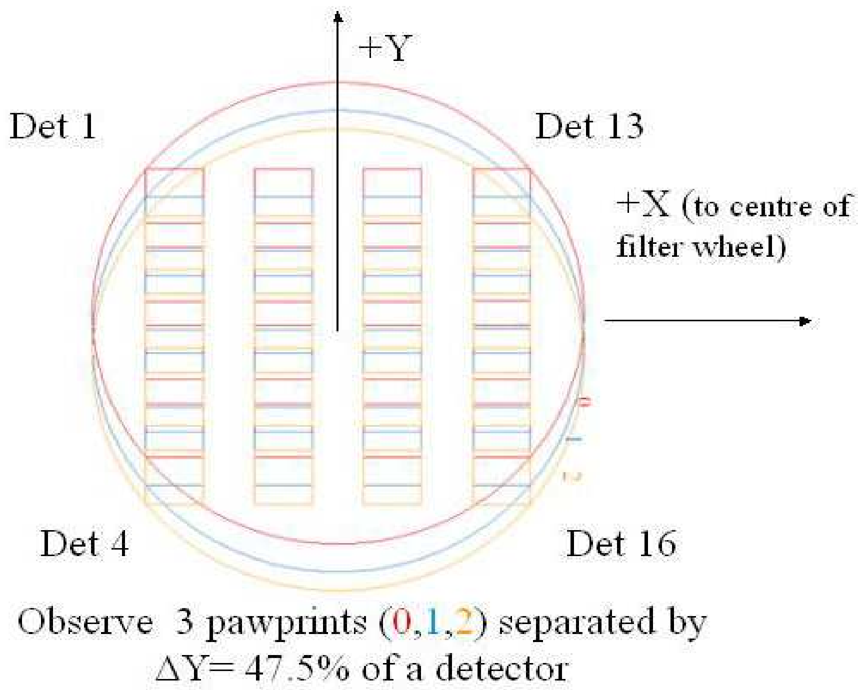


Figure 11: Completing a tile with six pawprints: the three vertical steps along the Y axis.

size.

Then, a position shift is made in X direction (Figure 12) so that the 2 positions in X cover a horizontal side 7.65 detector widths (=4+3$\times$0.90+0.95) with no strips at the +/$-$X edges. This corresponds to 1.475 degr (88.5 arcmin) at VISTA's nominal pixel size. Finally, the 3 steps in Y (described above) are repeated at the next position in X. So after 3x2=6 steps an area of 5.275x7.65=40.354 detector areas corresponding to 1.017 deg $\times$1.475 deg = 1.501 deg$^2$ sky is (almost) uniformly covered (by a minimum of 2 pixels) as shown in light green in the exposure time map below for a filled tile (no jitter). Figure 13 demonstrates how the 6-offset pattern is combined into a tile.

The telescope movements used to assemble a tile out of six pawprints are made with respect to the X,Y coordinates in the camera focal plane, not with respect to the celestial coordinates. Therefore, pawprints are not tilted with respect to their neighbors (unless such a tilt is specifically defined by the observer). Relative tilts among neighboring tiles in a multi-tile survey will be present, especially near the celestial poles (Sec. 6.5).

A map, showing the integration times accross the entire field of view, provided that the integration at each pointing is the same, is shown in Figure 14. The dark green areas at top and bottom of the plot are each 1.475 deg$\times$0.092 deg=0.135 sq. deg and can be overlapped by corresponding areas from adjacent tiles for many surveys. Assigning only one of the two 0.092 deg overlap (top & bottom) to each of the two tiles involved in an overlap, the result is that each tile, when part of a filled larger area, would cover (1.017+0.092)$\times$1.475=1.636 deg$^2$ which will be covered at least twice.

## 6.4 Scheduling Containers

The survey nature of the VISTA operation implies executing a large number of similar or even identical OBs (except for the target coordinates), necessary to obtain uniform coverage of wide sky areas. This complicates enormously the short-term scheduling of observations because of the number of sometimes conflicting requirements: timing and weather condition constraints, uniformity, and last

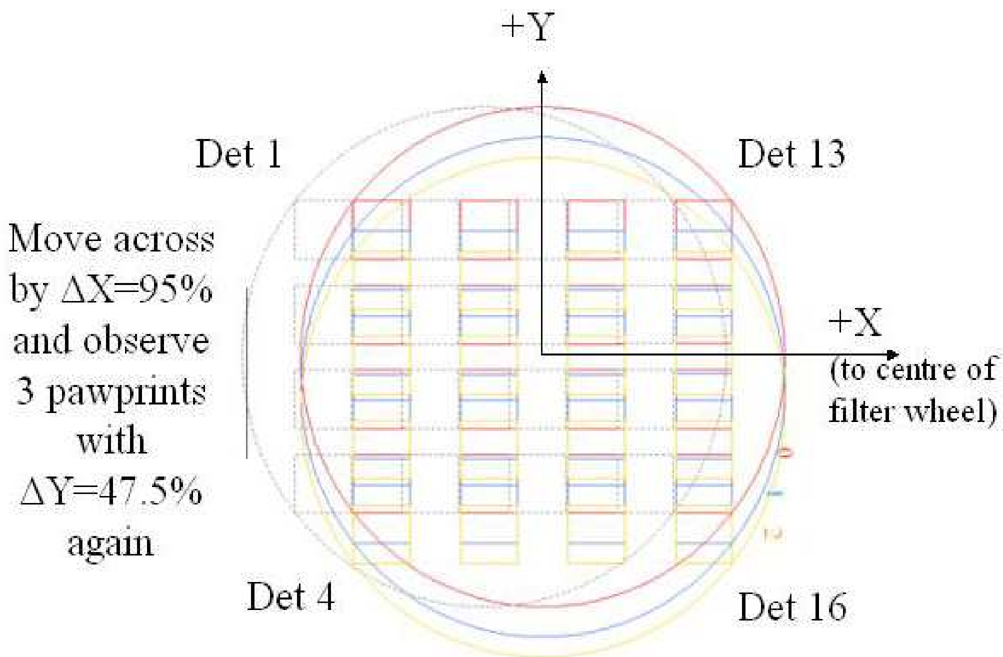


Figure 12: Completing a tile with six pawprints: the two horizontal steps along the X axis.

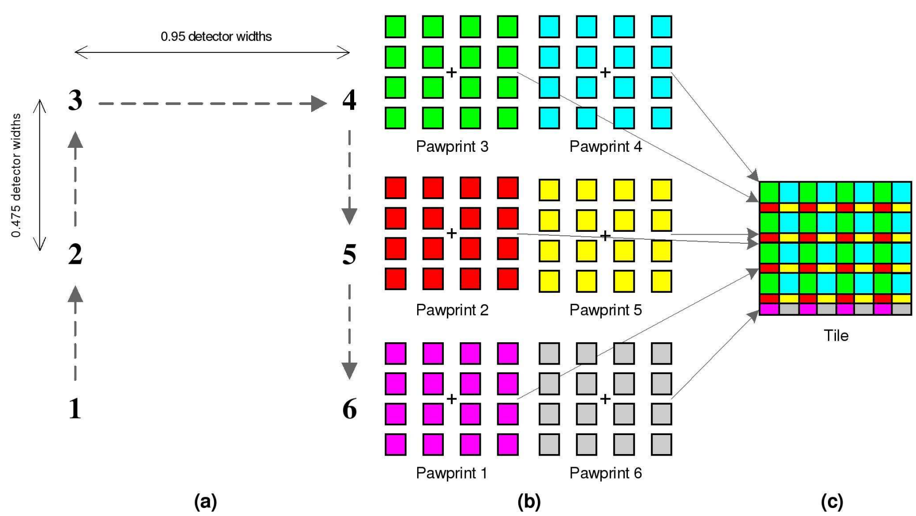


Figure 13: Contiguous tile, formed by combination of six overlapping pawprints.

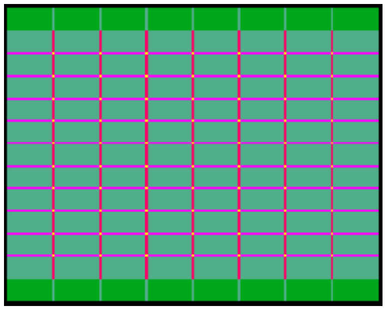

Figure 14: Exposure time coverage for a contiguous-coverage tile of 6 pawprints: dark green = 1, light green = 2, magenta = 3, red = 4, yellow = 6, in units of the single-pawprint exposure time.

but not least - the requirement to complete certain self-containing set of observations before starting a new one. A good strategic planning of a survey may ensure early science output long before the survey is completed.

The users are given tools for implementing the survey strategy called scheduling containers. They are high-level tools, with respect to the jittering, microstepping, etc., described in the previous Sec. 6.3. The containers allow to streamline the operations giving at the same time enough flexibility to achieve the scientific goals of the surveys.

Three types of scheduling containers are available forthe first year of VISTA operations:

– **Concatenations**: the member OBs are executed sequentially without interruptions, the order of execution is not specified; if a any of the OB in a concatenation is not executed, the entire concatenation must be repeated;

– **Time links**: the member OBs are scheduled whenever there is an upcoming time window defined by the users; the time windows are relative but after the execution of the first OB in a time link, they become absolute; the time link doesn't have to be repeated if any of the OBs can not be executed within the required time interval;

– **Groups**: the member OBs may be executed depending on the needs of the flexible scheduling of the observatory, but the OBs in the respective groups are dynamically reassigned higher and higher priorities depending on the rate of completion of a group, to increase the probability that a group that has been started, is completed before other groups are started.

See the SADT user manual more more detailed description of the scheduling containers.

## 6.5 Observing Strategy, Nesting

The observing strategy is determined by the science goals of the program, convolved with the limitations imposed by the technical and software features of the telescope and the camera. VISTA is a purpose-built survey telescope, so the VIRCAM's primary function is to produce a contiguous map of large sky areas using overlapping exposures.

The starting point in the survey design is to select a balance between the area, the depth, and the filter coverage. Next come the question of how to split the total integration time for each filter into different exposures, i.e. to select DITs, NDITs, microstepping and jittering patterns (see the discussion in Sec. 6.1.2). Finally, the user has to decide on the sequence in which the various observations will be obtained. For example, the filter rotation is relatively slow, ($\sim$21-40 sec for a filter exchange; see Sec. 6.8.5) and it might be more efficient to combine the observations of a few nearby tiles in the same filter in one scheduling container *group* that will likely lead to their consecutive execution, rather than to change the filter, and to re-observe the same tile multiple times. However, this strategy may leave the user waiting for some time before the observations in

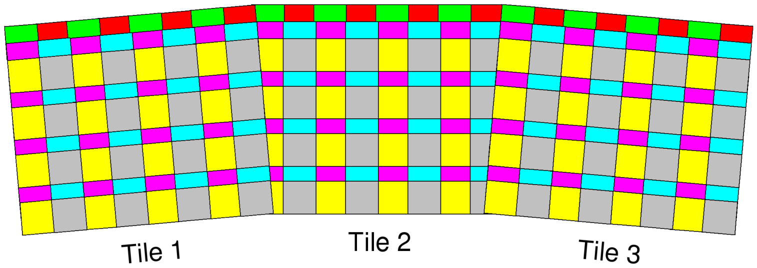


Figure 15: Example of a contiguous survey, containing three partially overlapping tiles. The curvature of the pawprint edges is ignored.

all filters of each tile are collected, and it will not ensure nearly-simultaneous multi-band photometry. The order in which various filters are observed in a tile should be optimized to shorten the filter wheel movements (see Sec. 5.3 for the filter order). The individual steps in this sequence of decisions are intertwined, and often can not be separated as clearly as described in this example.

The "tile" is the basic unit of a survey, being the smallest contiguous area of sky that the camera can image. A contiguous survey covers the required sky regions by tessellating tiles together with a small amount of overlap. The contiguous sky coverage can require some tiles to be tilted with respect to their neighbors, especially near the celestial poles (Figure 15). Minimizing the overlaps makes the survey more efficient, but some overlaps are desirable because they provide repeated measurements that can be used to verify the internal astrometric and photometric self-consistency of the survey.

The filters exchanges, pawprint patterns, jitters, and microsteps offsets can be executed in different order, called **nesting sequence**. Three nesting sequences are implemented:

**– FPJME :** construct the tile from a series of pawprints, repeating each pawprint with a different science filter. Within each pawprint execute a jitter pattern (if specified), and within each jitter pattern execute a microstep pattern (if specified).

**– PFJME :** construct the tile from a series of pawprints. Within each pawprint execute a jitter pattern, only this time repeat each jitter with a different science filter before moving on to the next. Within each jitter execute a microstep pattern (if specified).

**– FJPME :** construct the tile from a pawprint and jitter pattern such that one jitter observation is made from each pawprint in turn. Within each jitter pattern there can be a microstep pattern. The whole sequence may be repeated with different science filters.

The letters in these sequences stand for the following actions: **F** – set a filter, **P** – execute a pawprint pattern, **J** – execute a jitter pattern, **M** – execute a microstep pattern, and **E** – take an exposure.

The VISTA telescope system does not make any distinction between large movements (known at the VLT as "presets") and small movements (known at the VLT as "offsets"), so the telescope movements made by an acquisition template or by one of the observation templates are just as efficient. The data acquisition efficiency is not improved, for example, by combining tiles together in a single Observation Block (as long as the OBs are scheduled efficiently).

A number of measures can be undertaken to improve the survey efficiency:

– reject the manual autoguiding confirmation by setting AG.CONFIRM=F; then, the observing software will only seeks guide star confirmation from the operator when a failure is detected;

– skip verifying the reference position in the acquisition template using guide stars (set AG.START=F in the acquisition template), or make the reference position the same as the first pawprint position (i.e. begin each pawprint pattern with offset 0.0,0.0);

Table 5: VISTA sensitivities.

| Band | $Z$ | $Y$ | $J$ | $H$ | $K_S$ |
|---|---|---|---|---|---|
| Average sky brightness, mag arcsec$^{-2}$ | 18.2 | 17.2 | 16.0 | 14.1 | 13.0 |
| DIT at which the background alone saturates the detector, sec | 1207 | 787 | 197 | 36 | 26 |
| Atm. Ext. coeff., mag airmass$^{-1}$ | ??.? | ??.? | 0.1 | 0.08 | 0.08 |
| 5$\sigma$ in 15-min limiting mag (Vega=0) | ??.? | ??.? | 22.15 | 20.98 | 20.05 |

– use in the acquisition template the same filter as in the first science template, so the filter wheel movement is carried out in parallel with the telescope movement;

– minimize the filter movements in the science templates, if possible;

– use tile and jitter patterns which minimize the number of telescope movements, if possible;

– use the minimum total exposure time required for achieving the science goals of the survey;

– schedule the OBs to minimize telescope movements.

Further suggestions may be added as more experience of observing with VISTA is accumulated.

### 6.6 Autoguiding and AO operation

The autoguiding and the wavefront sensing are fully transparent to the user during the observations. However, earlier during the definition of the survey, the user must define GA/AO stars with the help of the Survey Area Definition Tool (SADT). The SADT finds the minimal number of tiles, necessary to cover a user-defined survey area. For each tile the SADT verifies the presence of suitable stars in the LOCS/AG field of view, and if this is not the case, it modifies the position of the tiles to ensure that such stars are available. The AG operation is not optional, having suitable guiding star is mandatory. Usually, as a result of this check, the number of tiles covering the survey area increases. This procedure is described in detail in the SADT User's Manual.

During normal operation, usually once at the beginning of the night the HOWFS are used to implement initial correction of the primary. Then, during the operation, the LOCS are used, in parallel with the observations if the telescope stays at one position more than $\sim$30 sec. This is the minimum time within which the LOCS can provide correction. In case of shorter observations, either the observations will have to be carried out without wavefront correction or the observations will have large overheads to derive and apply the corrections. For more details on the wavefront sensing see Section 5.4 and 5.5.

### 6.7 Sensitivity

The VISTA sensitivities for different filters are listed in Table 6. These values may change with time, check the VIRCAM web page for more up to date information.

### 6.8 Overheads

VISTA is intended to survey quickly, primarily through having a large field of view. The actual survey speed (in good conditions) depends on the adopted observing strategy. As with any telescope there are overheads associated with observing.

### 6.8.1 Overheads making a single tile in one filter

Overheads depend on the adopted combination, and order, of filter changes, microstepping, jittering, and tiling. To estimate the total execution time for an OB, one has to add to the total on-sky observing time the overheads for filter changes, microstepping, jittering, tiling, read-out overheads, as well as the overheads associated with the preset, the active optics and instrument set up. A summary of the VISTA overheads is given in Table 6. All these numbers will be updated to reflect the real behavior of the system. For recent updates, check the ESO VISTA web page.

### 6.8.2 Acquisition Overheads

On average, a full preset requires about two minutes, spent on:

– Slewing/presetting in altitude and azimuth;

– Rotator offset;

– Acquiring a guide star;

– Low order wavefront sensing (LOWFS) observation to update the M2 position;

– Instrument (i.e. filter wheel) set up.

To summarize: first, some time is necessary for the telescope movement: *20 sec + target distance / slew speed*, where the slew speed is 2 degr $s^{-1}$. Once the telescope completes its movement, the software must identify a guiding star, and the autoguiding and the wavefront sensing must be started. These three operations require 3, 5, and 45 sec, respectively. Finally, the instrument must be set up, which may take between 0 and 40 sec, depending on the lenght of the filter wheel movement. More detailed description of these overheads is given further. From point of view of the overheads, the change of tile is equivalent to a new acquisition.

### 6.8.3 Telescope and Rotator Movement Overheads

The time to go to a new tile depends on how far away it is in altitude and azimuth from the current position, and on the zenith distance. As for any alt-azimuth telescope at VISTA's latitude, one wants to minimize presets between objects with Dec$<-24$ degr to Dec$>-24$ degr and vice versa. Both altitude and azimuth PDUs can accelerate and decelerate the telescope at 0.5 degr $s^{-2}$ and the maximum angular velocity is 2 degr $s^{-1}$. Hence, it takes a 4 sec ramp-up to reach maximum angular velocity (and to move the telescope by 4 degr in those 4 sec).

The Cassegrain rotator is faster (acceleration/deceleration of 1 degr $s^{-2}$, and velocity of 3.6 degr $s^{-1}$ ) so it will hardly ever be the limiting overhead.

A small preset of 2 degr on-sky, in the worst case, can require a $\sim$60 degr azimuth move if alt=88 degr. Fortunately, a more "typical" case at alt=60 degr only requires a$\sim$4 degr azimuth move. Assuming an acceleration of 0.5 degr $s^{-2}$ for 2.82 sec followed by equal and opposite (de)celeration at same rate, this will take $\sim$5.84 sec (a smoother algorithm may take a bit longer so $\sim$10 sec is a more reasonable estimate). If the 2 degr movement is mostly along the Altitude it will be somewhat quicker.

The"worst case" preset is a 270 degr azimuth move from SE to NE which has to go the long way round via W due to the cable wrap, and which will take $\sim$140 seconds. These situations should be avoided, if at all possible, during scheduling.

### 6.8.4 Active Optics overheads

A Low Order Wavefront Sensor (LOWFS) is used to update the position of the secondary mirror during observations, and needs data for a minimum time of $\sim$30 sec to smooth out seeing variations. The LOWFS can operate in parallel with science observations.

Table 6: VISTA overheads.

| Action | Overhead, sec |
|---|---|
| Detector readout | 2.0 per DIT |
| Writing FITS to disk | 4.0 |
| Filter change | 21-40 |
| Jitter offset | 3.0 |
| Pawprint change | 10.0 |
| Micro step | 4.0 |

If the telescope is staying in one position for $>$30 sec there is no associated overhead as the LOWFS exposures merely start just after and finish just before the science integrations finish.

However using the LOWFS in this basic mode implies a minimum time between jitter moves of $\sim$30 sec. If it is essential to jitter more often than every 30 sec, this can be done using open-loop M2 control, though a slight loss of image quality may result. It is expected that after tracking the same sky area for $\sim$15 min one needs to do an LOWFS update.

In case that image quality falls off more quickly, or that one wants to observe for longer than X minutes before presetting to a new part of the sky, the telescope would have to stay where it was with the camera idle until the LOWFS has accumulated enough ($\sim$30 sec) exposure time.

As an alternative the AO control system could be changed in the future to internally coadd LOWFS frames to build up the necessary exposure from shorter exposures with the star moving on the LOWFS chip between exposures. This mode remains to be implemented and will then need to be tested on sky.

The initial AO set up requires about 45 sec. The LOWFS observation to update the M2 position may be needed after a telescope slew giving a large ($>$10 degr) change in altitude. It takes $\sim$30 sec for one closed-loop LOWFS cycle to complete and update the M2 position before science observing re-starts.

#### 6.8.5 Filter change overheads

The filter change time depends on the wheel rotation angle from the last position, and it varies. To move between two:

– neighboring filters – 21 sec;

– filters separated by one position – 27 sec;

– filters separated by two positions – 33 sec;

– filters separated by three positions – 40 sec.

Larger offsets are not needed because they can be accomplished by a shorter movement of the wheel in the opposite direction. The filter changes can be done in parallel with the position change, to save time.

### 6.9 Science Observation Overheads

In addition to the overheads for offsettting, AG and AO setting up discussed before, the science observations accumulate overheads for microstepping, detector readout, merging and storing FITS files. These are listed in Table 6.

## 6.10 Calibration Plan

There are four types of VIRCAM calibrations, related to:

- properties of the transfer function (image in, ADUs out) of the end-to-end system (telescope, camera, IR detector system including associated controllers, etc.) so that **instrumental signature can be removed from the data**. As VISTA has a wide field of view, particular attention must be paid to variations of the transfer function across the field;
- **photometric zero points and extinction coefficients** corresponding to the images. The expected accuracy is a few percent.
- **astrometric distortions** of the images; the nominal astrometric calibration is based on the 2MASS PSC. 2MASS astrometry is derived from direct calibration to TYCHO 2, and it is in the ICRS system (note thatthis requires RADECSYS = ICRS in the FITS headers). It is known to have average systematic errors smaller than $\sim$100 mas and RMS errors smaller than $\sim$100 mas, for all point sources with S/N$>$10.
- generating **Quality Control measurements** for monitoring the instrument health and performance, and the weather conditions; for example, the FWHM of the stellar images verifies the instrument alignment, the quality of the AO correction, and the seeing conditions.

Generally, obtaining the necessary calibrations is responsibility of the Science Operations Department. The users can only submit OBs for: (i) photometric standard star observations, and (ii) observations of astrometric fields. We list here the rest of the calibrations for completeness only.

The photometric observations will be tagged as calibration by the data flow system, according to the key words written in the fits header by the template. The astrometric fields will be tagged as science data. The pipeline will provide astrometric solution for them as for all other science frames, based on the 2MASS.

### 6.10.1 Instrument signature removal

The aim of these calibrations is to provide pawprints as though taken with a perfect camera, which produces a photometrically linear, evenly illuminated, though sparsely sampled, reproduction of the sky, free of any instrument and detector defects. The calibration cascade is shown in Figure 16, and details of the individual calibrations are summarized in Table 7. Note that all calibrations must be repeated after instrument intervention, regardless of the age of the last calibrations. The raw output of all calibrations are one or more fits files. They are processed by the corresponding pipeline recipes to produce either FITS file products, or systems of calibration coefficients. Calibration data:

**(1) Reset Frames** measure the variation of the reset pedestal over the period between two exposures. Therefore, the calibration is a Reset-Read sequence taken with the minimum DIT plus the 5-8 sec overheads during which the IRACE processes an integration and starts the next one. A typical sequence might be 5$\times$10 sec exposures. Note that this is different from a dark frame, which consists of a Reset-Read-Read sequence where the output is the difference of the two reads. The aim here is to map the effect of the reset and to trace any drift of the pixel level after a reset, so each new reset frame is compared with a historical one from a database to detect changes. The pipeline outputs is a variance with respect to the “standard” frame (a QC parameter).

**(2) Dark-Current Frames** are dark frames taken with increasing DITs, used to measure the detector dark current by fitting a median slope to dark values versus DIT for each pixel, to produce a dark-current map. The range of DITs starts at MINDIT, and finishing at a large value, depending only on the available time for this calibration. The pipeline outputs calculates an array of detector dark currents for each individual pixel (a QC parameter).

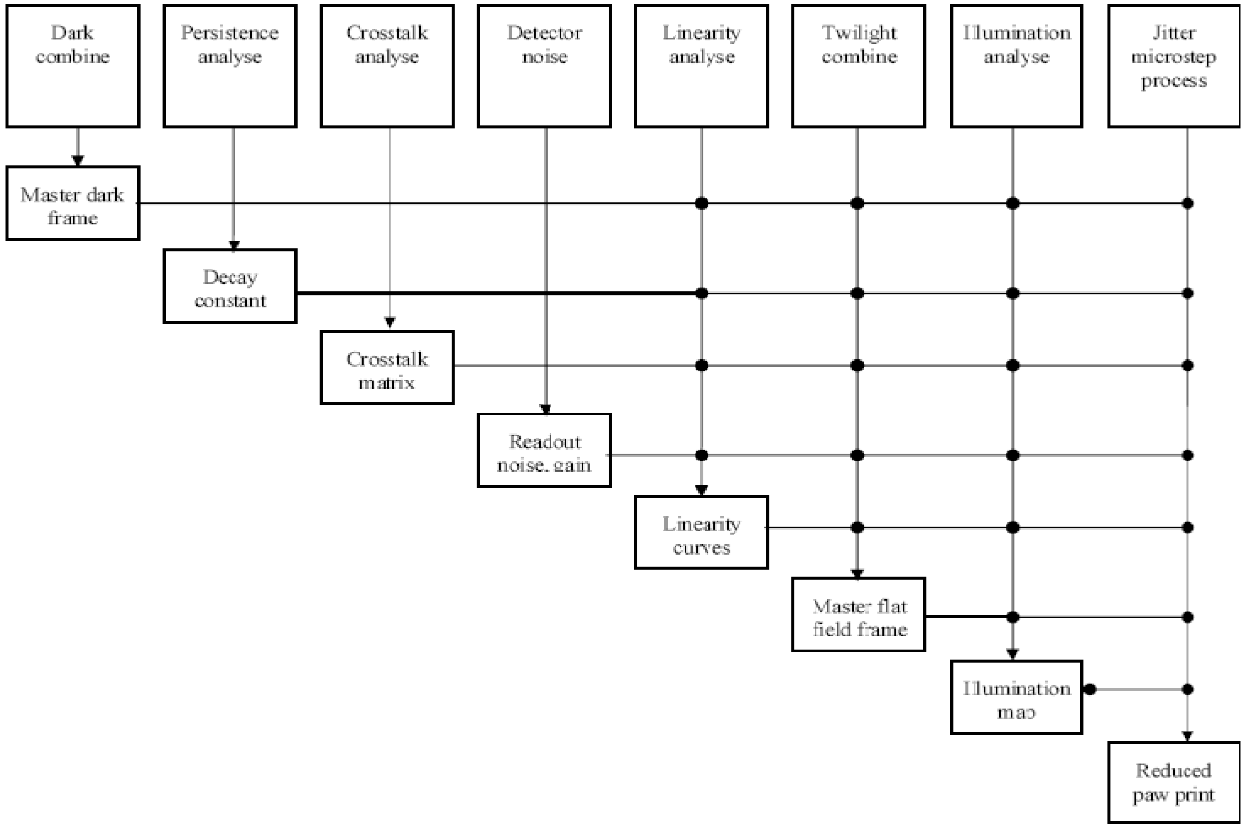


Figure 16: VIRCAM cascade diagram for producing calibration frames.

**(3) Dark Frames** are exposures with cold blank filters completely blocking the detectors from incoming radiation. They are used to calibrate out and measure two separate additive effects: (i) the thermal dark current, and (ii) the "reset anomaly" (a residual structure left in the image after the reset is removed in the DAS, when it does a correlated double sample Reset-Read-Read).

They are additive and can be removed together, using dark frames taken with **the same DIT×NDIT as the observation that need to be calibrated**, assuming that the two effects are stable on time scale of the lenght of the exposures. Usually, for astronomical detectors they are stable on time scale of days. To minimize contamination from transient events, the darks are combinations of many frames with appropriate rejection.

The total duration of the calibration depends on the number of DIT×NDIT combinations that need to be calibrated – one set of calibrations must be taken for each set of observations. The pipeline outputs are a mean dark fits frame, and some QC parameters (dark current signal plus reset anomaly stability measurement, detector dark current, and detector particle event rate).

**(4) Dome flats** are used for instrument performance monitoring, evaluation of the image structure, making bad pixel masks, and producing confidence maps. **They are not used for gain correction (flat-fielding) due to non-uniform illumination of the screen, and the different colour of the illumination compared with the night sky.** The dome flats are a series of timed exposures of the dome screen taken through a given filter, in conditions that exclude variable or excessive ambient light (i.e., no working in the dome during the dome flats). The illumination/exposure times are adjusted to yield ∼20,000 ADU (i.e. nearly half of the potential well depth of 50,000 ADU). The pipeline outputs are: a master dome flat for the given filter, bad pixel mask, and a number of QC parameters (number of saturated pixels, lamp efficiency, etc.)

**(5) Detector Noise** calibration – measures the readout noise and the gain of each chip, for purpose of detector health monitoring. Furthermore, these are used by the pipeline in some pixel rejection algorithms, i.e. during the combination of individual jittering science frames.

These properties are measured from a pair of dome flats, and a pair if darks (matching the DIT×NDIT of the flats). The flats must be exposed to give ∼20,000 counts (mid-range). The pipeline calculates readout noise and gain estimates for each read-out channel of each detector (QC parameters).

**(6) Linearity** curve of each detector can be determined through a series of ∼20 dome flats taken

Table 7: Summary of the calibrations. The columns contain: type of calibration, phase of the observations when the calibration is obtained, frequency of repetition, duration of the calibration, templates used to obtain the calibration, and the pipeline recipe used to process the calibration data. The duration of flats for narrow band filters is be longer than the given numbers because of the lower transmission. The duration of the persistence and the cross-talk depends on the presence of bright stars in the field and may be longer if there are no enough of them to cover all detectors. Some calibrations are determined continuously from the science data, as opposed to others that are measured only as needed.

| Calibration | Phase | Freq. | Duration | Template | Pipeline Recipe |
|---|---|---|---|---|---|
| | | | Calibrations for instrument signature removal: | | |
| Reset Frames | Daytime | Daily | 2 min | VIRCAM_img_cal_reset | vircam_reset_combine |
| Dark-Current Frames | Daytime | Daily | 10 min–2 hr | VIRCAM_img_cal_darkcurrent | vircam_dark_current |
| Dark Frames | Daytime | Daily | 10 min–2 hr | VIRCAM_img_cal_dark | vircam_dark_combine |
| Dome Flats | Daytime | Weakly | 15 min/filter | VIRCAM_img_cal_domeflat | vircam_dome_flat_combine |
| Detector Noise | Daytime | Daily | 1 min | VIRCAM_img_cal_noisegain | vircam_detector_noise |
| Linearity | Daytime or cloudy night | Monthly | 1 hr/filter | VIRCAM_img_cal_linearity | vircam_linearity_analyse |
| Twilight Flats | Twilight | Weakly | 15 min/filter | VIRCAM_img_cal_twiflat | vircam_twilight_combine |
| Illumination Correction | Night | Monthly | 30 min/filter | VIRCAM_img_cal_illumination | vircam_mesostep_analyse |
| Persistence | Night | Monthly | >10 min | VIRCAM_img_cal_persistence | vircam_persistence_analyse |
| Cross-Talk | Night | Monthly | >10 min | VIRCAM_img_acq_crosstalk, VIRCAM_img_cal_crosstalk | vircam_crosstalk_analyse |
| | | | Calibrations for photometric standard star observations: | | |
| Standard star | Night | Nightly | 5 min/filter every 2 hr | VIRCAM_img_cal_std | vircam_standard_process |
| | | | Calibrations for astrometric distortions: | | |
| Astrometric Correction | Night | Nightly | in parallel | all science templates | vircam_jitter_microstep_process |
| | | | Calibrations derived from the science data: | | |
| Night-Sky Maps | Night | Contin. | in parallel | N.A. | vircam_jitter_microstep_process |
| Sky Subtraction & Defringing | Night | Contin. | in parallel | N.A. | vircam_jitter_microstep_process |
| Jittering Offsets | Night | As needed | in parallel | VIRCAM_img_obs_paw, VIRCAM_img_obs_tile, VIRCAM_img_obs_offsets | vircam_jitter_microstep_process |
| Microstepping | Night | As needed | in parallel | VIRCAM_img_obs_paw | vircam_jitter_microstep_process |
| Opt. Distortion | Night | Contin. | in parallel | | |
| WCS Fit | Night | Contin. | in parallel | | vircam_jitter_microstep_process |

under constant illumination, at varying exposures, starting at MINDIT, up to just into saturation for all chips. The illumination is set to produce $\sim$1000 ADU at MINDIT.

The constant screen illumination requirement implies that the dome flats cannot be taken in conditions of variable or excessive ambient light, i.e. no work in the dome is allowed during the linearity calibration. Check frames of constant exposure are intertwined with the “ramp” exposures to monitor the screen illumination. Alternate runs of this procedure should use increasing and decreasing sets of exposure times or take exposures with different exposure times in a randomized non-monotonic order. The pipeline calculates linearization curves and polynomial coefficients, bad-pixel maps, and various QC parameters such as measurement of non-linearity, and bad pixel statistics.

**(7) Twilight Flats** remove pixel-to-pixel gain variations and the instrumental vignetting profile for a given filter. They also provide a global gain correction between the 16 detectors and between the 16 individual read out channels within each detector (giving a total of 256 channels). The mean flat-fields and bad-pixel maps are sources for the confidence map that are part of the final science-level data products. These confidence maps are in effect combined weight maps where the mean level is normalized to 100%, and bad pixels are set to zero - an important pre-requisite for the deep stacking and tiling of the individual pawprints, and for calculating the statistical significance of detected objects.

Twilight sky flats have a good (but not perfect) colour match to the night sky observations we wish to correct, and can be taken under conditions where the contribution from night sky fringing, emission from dust particles on the optical surfaces, and other spatial effects are mostly negligible or match best the conditions for the science data. The slightly imperfect colour match between the twilight and night sky will cause a very small residual error in the gain correction.

The sky level must be low enough to avoid saturating a MINDIT exposure, but high enough so the emission from fringing or dust on the optical surfaces will be negligible in comparison with the sky level, leaving only a short interval in which to acquire the twilight flats. Therefore, it will not always be possible to get a complete set of twilight flats every night, especially during service observations using many filters or on cloudy nights. Pre-selected “empty” twilight fields will be observed on **clear** night, and offsets between the individual exposures will be executed to cancel the effect of bright stars in the field. The pipeline output includes mean twilight flats, confidence maps, and differences with respect to a reference flat for all detectors and channels (QC parameters).

**(8) Illumination Correction** is necessary to remove any large-scale background variations which cannot be modelled or removed via the twilight flat-fielding. Typically, they are caused by vignetting within the focal plane and scattered light within the camera. Dividing a target frame by a flat-field that is affected by these will cause systematic photometric errors across the FOV. The illumination correction is a mapping of the spatial systematic effects across FOV so that a correction map can be factored into the final photometry as a function of the location of the object in the FOV.

The illumination correction is derived either from observations of a secondary photometric standard field with a density of 100-200 star per detector, or from a grid (spanning the entire FOV) of observations of a single relatively bright (to shorten the observations) standard. Then, the illumination correction is a position-dependent scale factor derived from the spatial variation of the photometric zero-point across the FOV. The illumination correction is derived for each filter, and in **photometric conditions**.

**(9) Image Persistence** (or “remanence”, “memory”) is a detector feature causing residual traces of images from a preceding exposure on the current image. It is measured observing a fairly empty field (to avoid confusion with the cross-talk effects) with a close to saturated star, followed by a sequence of dark frames to measure the characteristic decay time of the remnant from the star. This must be done for each detector or even for each readout channel. The pipeline product is a set of persistence constants.

**(10) Electrical Cross-Talk** is a feature of the electronics causing traces of images from a star on one detector/channel on another detector/channel. To measure it, a saturated star is placed on a channel, and the effect it causes on all other 255 channels is measured. The result is a 256×256 cross-corelation matrix, the majority of whose elements are nearly zero – the cross-talk between different detectors is anticipated to be smaller than between the channels within a detector. Currently, for most purposes the cross-talk of the VIRCAM is negligible but it is monitored routinely for detecting any changes. The pipeline calculates a cross-talk matrix, and an average of the off-diagonal components (a QC parameter).

### 6.10.2 Photometric Calibration

The camera will be on the telescope semi-permanently, providing a stable configuration that enables a long-term approach to photometric calibration to be taken. The strategy is to define robust routine calibration procedures, so that the accuracy, and hence the scientific value, of the archive, will be maximized. Zero points – defined as magnitudes at airmass unity which yield flux of 1 count/sec on the detector – will be determined in the Vega system via two independent methods:

**(1) Calibration from 2MASS**: the photometric zero point is derived individually for each image from measurements of stars in the 2MASS Point Source Catalog (PSC) by solving the equation for each filter and detector:

$$ZP_{VIRCAM} + m_{instr} - m_{2MASS} = CT(J-H)_{2MASS} + const \qquad (1)$$

for all common stars above a threshold signal-to-noise in the PSC and unsaturated in VIRCAM. Here $ZP_{VIRCAM}$ is the VIRCAM zero point, $m_{instr} = -2.5 \times log_{10}(counts/sec)$ is the VIRCAM instrumental magnitude, $m_{2MASS}$ is the 2MASS PSC magnitude, $(J-H)_{2MASS}$ is the 2MASS PSC star color, and $const$ is an offset which may be required to transfer some passband to the Vega system.

**(2) Calibration from Standard Star Fields**: for any standard star $i$ in any filter $b$:

$$m_{ib}^{cal} = m_{ib}^{instr} + ZP_b - k_b \times (X_i - 1) \qquad (2)$$

where $m_{ib}^{cal}$ is the calibrated instrumental magnitude in the system of the standard star, $m_{ib}^{inst} = -2.5 \times log_{10}(counts/sec)$ is the measured instrumental magnitude, $ZP_b$ is the Zero Point, $k_b$ is the atmospheric extinction coefficient, and $X_i$=$sec\, z_i$ is the airmass of the standard star during the observation. It is assumed here that the second-order atmospheric extinction term and the colour-dependency of $k_b$ are both negligible.

Typically, ZPs are stable throughout a night (if photometric), but over months the ZPs decrease (i.e. the sensitivity of the instrument is reduced), for example due to accumulation of dust on the primary mirror. The extinction coefficients $k_b$ are usually stable over periods of months but they will be monitored through each night assuming fixed ZPs and making measurements over a range of airmass. The 2MASS found that their extinction coefficients vary seasonally but such an effect should be smaller for VISTA because of the drier site and narrower filter profiles, especially at $J$.

A network of secondary photometric standard fields is set up so routine photometric standard observations can be made every two hours. The fields are selected among the 2MASS touchstone fields (Figure 17) and UKIRT faint standard fields. Some of them have already been observed and calibrated in by WFCAM at the UKIRT. The secondary fields meet the following criteria:

(1) cover the camera pawprint area;

(2) span RA=0–24 hr, with an approximate spacing of 2 hrs

(3) enable observations over a range of airmass, i.e. some fields pass close to the VISTA zenith, and others are available to the North (to allow for WFCAM cross-coverage) and South to optimize telescope azimuth slewing and to allow observations during strong wind from different directions;

(4) contain ∼100 stars per detector to allow characterizing the systematic position-dependent photometric effects (but avoiding crowding problems), with $J$≤18, and $K_S$ ≤16 mag for short exposures;

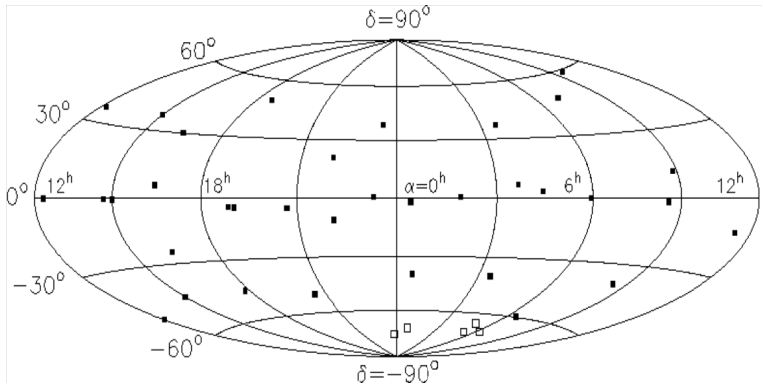


Figure 17: Distribution of the 2MASS touchstone fields on the sky.

(5) encompass stars with broad ranges of colours to allow derivation of extinction colour terms and to facilitate transformations from/to other filter systems.

**Photometric Standard Field Calibration** is obtained with a template (Table 7) that sets the header DPR keywords so the pipeline can identify the raw fits files as standard star observations, and to process them accordingly. The pipeline output is: ZP, Atmospheric Extinction coefficient, Atmospheric Extinction Color Term, Illumination Correction, and a Global Gain Correction.

### 6.10.3 Astrometric Calibration

The astrometric calibration provides the transformation between pixels coordinates of instrument-signature free pawprints and celestial coordinates for all 16 sub-images, leaving the pawprints on the appropriate photometric scale. The transformations are saved in a Flexible-Image Transport System (FITS) World-Coordinate System (WCS) header keywords. Zenithal Polynomial Projection (ZPN) is used (Calabretta & Greisen 2002, A&A, 395, 1077).

The strongest term in the optical-distortion model is the cubic radial term, and the distortions are colour (i.e. filter) dependent. Because of the distortion, it is necessary to carry out non-linear pixel re-sampling before combining images taken at different jittering positions. The radial scale variation due to the distortion has also an impact on photometric measurements, inducing an error up to 3.5% in the corners of the field, compared to the center.

The WCS distortion terms are measured from on-sky observations, based on the 2MASS PSC astrometry, in the system of the International Coordinate Reference Frame (ICRF). The astrometric calibration is carried in parallel with the observations and doesn't require dedicated time (Table 7).

The camera software writes an initial WCS keywords values into the FITS headers of each raw data frame based on the guide star position. The accuracy is better than 2 arcsec, and it depends on the guide star coordinates accuracy, and the accuracy with which the camera geometry is known. After the instrumental-signature removal the pipeline uses this initial approximation as a starting point for orientation of the data frames and location of astrometric stars for a full WCS solution that provides refined scientific quality astrometry. The astrometric stars are centroided in the data frames to typically 0.1 pixel accuracy. The uncertainty of the final astrometric solution comes from the RMS of the fit, and the known systematics of the reference catalog.

The pipeline output includes refined WCS FITS header keyword values for all frames, and some QC parameters (i.e. pointing accuracy, calculated from equatorial coordinates computed at the particular location using the fitted WCS and the initial WCS that was written to the raw header).

### 6.10.4 Additional Calibrations Derived from Science Data

The procedures described in this section and summarized in Table 7 are calibrations only in a broader sense – they are rather data reduction steps, related to the astrometric calibrations of the data. They are derived from raw data FITS files during the regular data flow, i.e. do not require dedicated observations and extra overheads. Their purpose is to remove the instrument-signature, i.e. the sparce sky coverage of the individual pawprints or the cosmetic defects of the detectors.

**(1) Sky Subtraction and Defringing** removes the well known sky background variations over large scale in the IR, and the fringing and thermal emission from local dust particles on the optical surfaces. The sky maps are formed either from the target frames (if the target field is sparce) or from any special offset sky frames (for crowded fields or extended targets) by combining frames over an appropriate time range (determined by the sky flat stability), with appropriate rejection. The pipeline also produces fringe and dust maps.

**(2) Dark Sky Flats** may be constructed from the dark sky maps. Their advantage over twilight flats is the better colour match to the average astronomical object, minimizing the sensitivity of the gain and flat-field correction to differential colour terms with respect to astronomical objects. However, fringing and thermal emission from dust particles on the optical surfaces need to be removed because they can be high enough to affect the background significantly in some passbands, leading to systematic errors in photometry.

**(3) Jittering** removes detector cosmetic defects and cosmic ray hits, and allows to create sky maps, while accumulating sufficient signal to achieve the required S/N. The flat fielding is also improved because the flux coming from a given point on the sky is averaged over the response of many different pixels. For jittering, the total requested exposure is split into several shorter exposures (at least 5, to obtain good sky maps) with random or predefined telescope offsets between them. It is similar to microstepping, but with coarser sampling, and the pipeline combines the jittered exposures with a rejection algorithm. The pipeline combines the jittered frames, after removing the other instrument signatures, and produces a combined frame and confidence maps.

**(4) Microstepping** improved the sampling by *non-integer sub-pixel offsets*. It is critical when the point-spread function is under-sampled (under seeing better than 0.68 arcsec). It improves the flat fielding, same as jittering. Unlike the jittering, the pipeline interleaves the microstepped exposures without rejection. There is a number of predefined microstepping patterns (i.e. $2\times2$ pattern, with 0.5 pixel spacing). Microstep patterns can be nested within each jitter position. The pipeline combines the microstepped frames and produces confidence maps.

# 7 Data Flow, Pipeline, Quality Control

The mean VISTA data volumes are exceptionally high (estimated $\sim$315 GByte on a typical night) because of the multiple short exposures, usual for IR observations. This makes it challenging to reduce the data at the telescope, or even to carry out fully just the primary data reduction (sky subtraction, flat fielding). Only partial processing is carried at the telescope, for preliminary quality control purposes.

The data are transfered to the ESO archive by shipping physically disks from Paranal to Garching. The nominal delivery time is 1-2 weeks. Individual pawprints are processed by a ESO pipeline that creates first master calibrations, and uses them for higher level quality control and trend analysis.

These reductions are done on the pawprint level without combination of pawprints into tiles. Immediately after the data pass quality control, the raw frames become publicly available. Further data reduction is carried out by the users outside of ESO. The users can also upload high-level data products into the ESO Archive to make them available to the community.

The object extraction is vital for astrometric and photometric calibrations of the data, and it is rigorously monitored during the quality control process. The pipeline extracts objects from each frame, and classifies them as stellar, non-stellar or noise. A number of QC parameters are associated with every object: mean sky background, mean sky noise, number of noise objects, mean seeing, mean stellar ellipticity, etc.

The quality control adds no overhead to the observations. A list of quality control parameters is given in Table 8).

# 8 References

This manual was based on many VPO documents, among which was the *VISTA IR Camera Software User and Maintenance Manual* (VIS-MAN-ATC-06080-0020), Version 2.8 from 29-April-2008, prepared by Steven Beard. The introduction and the general IR imaging sections are partly based on the SofI and SINFONI user manuals.

Table 8: Quality Control Parameters.

| Parameter, units | Description |
|---|---|
| QC.APERTURE_CORR [mag] 2 arcsec diam aperture flux correction. | The aperture flux correction for stellar images due to flux falling outside the aperture. Determined using a curve-of-growth of a series of fixed-size apertures. Alternative simple measure of image profile properties, particularly the presence of extended PSF wings, as such monitors optical properties of system; also required for limiting magnitude computations. |
| QC.BAD_PIXEL_NUM Number of bad pixels/detector. | Determined from the statistics of the pixel distribution from the ratio of two flatfield sequences of significantly different average count levels. The number of bad pixels per detector (hot or cold) should not change |
| QC.BAD_PIXEL_STAT Fraction of bad pixels/detector. | Determined from the statistics of the pixel distribution from the ratio of two flatfield sequences of significantly different average count levels. The fraction of bad pixels per detector (either hot or cold) should not change |
| QC.CROSS_TALK Average values for cross-talk component matrix. | Determined from presence of +ve or -ve ghost images on other channels/detectors using exposures in bright star fields. Potentially a fully populated 256x256 matrix but likely to be sparsely populated with a small number of non-zero values of band-diagonal form. This QC summary parameter is the average value of the modulus of the off-diagonal terms. Values for the cross-talk matrix should be very stable with time, hardware modifications notwithstanding. |
| QC.DARKCURRENT [ADU $s^{-1}$ec] Average dark current on frame. | Measured using the median of the pixel values, can later be compared similar darks for trends |
| QC.DARKDIFF_MED [ADU] Median new-library dark frame. | Measure the median of the difference of a new mean dark frame and a library reset frame |
| QC.DARKDIFF_RMS [ADU] RMS new-library dark frame | Measure the RMS of the difference of a new mean dark frame and a library dark frame. |
| QC.DARKMED [ADU] Median dark counts | Median counts in a dark frame. |
| QC.DARKRMS [ADU] RMS noise of combined dark frame. | RMS is defined here as the Gaussian equivalent MAD i.e. 1.48×median-of-absolute-deviation from median. The RMS can later be compared with library values for darks of the same integration and exposure times. |
| QC.ELLIPTICITY Mean stellar ellipticity. | The detected image intensity-weighted second moments will be used to compute the average ellipticity of suitable signal-to-noise stellar images. Shot-noise causes even perfectly circular stellar images to have non-zero ellipticity but more significant values are indicative of one of: optical, tracking and auto-guiding, or detector hardware problems. |
| QC.FLATRATIO_MED Median new/library flat frame. | Measure the median of the ratio of a new mean flat frame and a library flat frame. |
| QC.FLATRATIO_RMS_RMS new/library flat frame. | Measure the RMS of the ratio of a new mean flat frame and a library flat frame. |
| QC.FLATRMS_RMS flat-field pixel sens per detector. | RMS is defined here as the Gaussian equivalent MAD i.e. 1.48×median-of-absolute-deviation from unity after normalizing by median level i.e. measuring the RMS sensitivity variation. The RMS can later be compared with library values for troubleshooting problems. significantly with time. |
| QC.FRINGE_RATIO Ratio of sky noise before/after fringe fit | A robust estimate of the background noise is done before the first fringe fitting pass. Once the last fringe fit is done a final background noise estimate is done. This parameter is the ratio of the value before fringe fitting to the final value after defringing. |
| QC.GAIN [$e^-$/ADU] Gain. | Determined from pairs of darks and flatfields of the same exposure/integration time and illumination by comparing the measured noise properties with the expected photon noise contribution. The gain of each detector should remain stable so long as the electronics/micro-code have not been modified. |

| Parameter, units | Description |
|---|---|
| QC.GAIN_CORRECTION Detector median flat-field/global median. | The ratio of median counts in a mean flat exposure for a given detector relative to the ensemble defines the internal gain correction for the detector These internal relative detector gain corrections should be stable with time. |
| QC.HOTFRAC Fraction of hot pixels | The fraction of the pixels on an image that are estimated to be hot. |
| QC.IMAGE_SIZE [arc-sec] Mean stellar image FWHM. | Measured from the average FWHM of stellar-classified images of suitable signal:to:noise. The seeing will obviously vary over the night with time, wavelength (filter) and as airmass$^{0.6}$. This variation should be predictable given local site seeing measures. A comparison with the expected value can be used as an indication of poor guiding, poor focus or instrument malfunction. |
| QC.LIMITING_MAG [mag] Limiting mag i.e. depth of exposure. | Estimate of 5-sigma limiting mag for stellar-like objects for each science observation, derived from QCs ZPT_2MASS, SKY_NOISE, APERTURE_CORR. Can later be compared with a target value to see if main survey requirements (i.e. usually depth) are met. |
| QC.LINEARITY Percentage average non-linearity. | Derived from measured non-linearity curves for each detector interpolated to 10,000 counts (ADUs) level. Although all IR systems are non-linear to some degree, the shape and scale of the linearity curve for each detector should remain constant. A single measure at 10,000 counts can be used to monitor this although the full linearity curves will need to be examined quarterly [TBC] to look for more subtle changes. |
| QC.LINERROR_RMS percentage error in non-linearity measure | Derived from the RMS of the a line fit to linearized fluxes versus exposure time and applied to a nominal level of 10,000 counts. |
| QC.MAGNZPT Number of stars in zero point calculation. | The number of stars on this image used to calculate the photometric zeropoint. |
| QC.MAGZERR [mag] Photometric zero point error. | A measure of the RMS photometric zero point error using an aperture of 1.4 $\times$ [TBC] the core radius. |
| QC.MAGZPT [mag] Photometric zero point. | A measure of the photometric zero point using an aperture of 1 $times$ the core radius. |
| QC.MEAN_SKY [ADU] Mean sky level. | Computed using a clipped median for each detector Sky levels (perhaps not at $K_S$), it should vary smoothly over the night. Strange changes in values may indicate a hardware fault (i.e. filter misplacement). |
| QC.NHOTPIX Number of hot pixels | The number of detected hot pixels on an image |
| QC.NOISE_OBJ Number of classified noise objects per frame. | Measured using an object cataloguer combined with a morphological classifier. The number of objects classified as noise from frame-to-frame should be reasonably constant; excessive numbers indicate a problem. |
| QC.PARTICLE_RATE [count/s/detector] Cosmic ray/spurion rate. | Average number of pixels rejected during combination of dark frames, used to give an estimate of the rate of cosmic ray hits for each detector. This can later be compared with previous estimates and monitored. |
| QC.PERSIST_DECAY [s] Mean exponential time decay constant. | The decay rate of the persistence of bright images on subsequent exposures will be modelled using an exponential decay function with time constant tau. Requires an exposure on a bright star field followed a series of darks. |
| QC.PERSIST_ZERO Fractional persistence at T0 (extrapolated). | Determined from the persistence decay behavior from exponential model fitting. Requires an exposure on a bright star field followed a series of darks (as above) |
| QC.READNOISE [e-] Readnoise. | Measured from the noise properties of the difference in two consecutive dark frames, using a MAD estimator as above for robustness against spurions. The noise properties of each detector should remain stable so long as the electronics/micro-code have not been modified. |
| QC.RESETDIFF_MED [ADU] Median new-library reset frame. | Measure the median of the difference of a new mean reset frame and a library reset frame. |

| Parameter, units | Description |
|---|---|
| QC.RESETDIFF_RMS [ADU] RMS new-library reset frame | Measure the RMS of the difference of a new mean reset frame and a library reset frame. |
| QC.RESETMED [ADU] Median reset level | Median reset level |
| QC.RESETRMS [ADU] RMS noise in combined reset frame. | Variation is defined here as the Gaussian equivalent MAD i.e. 1.48×median-of-absolute-deviation from unity after normalizing by median level i.e. measuring the RMS reset level variation. The RMS can later be compared with library values for troubleshooting problems. |
| QC.SATURATION [ADU] Saturation level of bright stars. | Determined from maximum peak flux of detected stars from exposures in a standard bright star field. The saturation level×gain is a check on the full-well characteristics of each detector. |
| QC.SCREEN_STEP Maximum percentage jump in monitor images | Derived from the median flux in each of the monitor exposures (if they are done). This is the maximum percentage jump between adjacent exposures in the monitored sequence. |
| QC.SCREEN_TOTAL Total percentage variation in monitor images | Derived from the median flux in each of the monitor exposures (if they are done). This is the percentage variation over the whole of the sequence of exposures |
| QC.SKY_NOISE [ADU] RMS sky noise. | Computed using a MAD estimator with respect to median sky after removing large scale gradients. The sky noise should be a combination of readout-noise, photon-noise and detector quirks. Monitoring the ratio of expected noise to measured one provides a system diagnostic at the detector level. |
| QC.STRIPERMS [ADU] RMS stripe pattern | The RMS of the stripe pattern removed from an image |
| QC.WCS_DCRVAL1 [deg] Actual WCS zero point X - raw header value. | Measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-parameter detector model offset. |
| QC.WCS_DCRVAL2 [deg] Actual WCS zero point Y - raw header value. | Measure of difference between dead-reckoning pointing and true position of the detector on sky. Derived from current polynomial distortion model and 6-parameter detector model offset. |
| QC.WCS_DTHETA [deg] Actual WCS rotation PA - raw PA header value(h). | Measure of difference between dead-reckoning PA and true position angle of the detector. Derived from current polynomial distortion model and 6-parameter detector model effective rotation term. |
| QC.WCS_RMS [arcsec] Robust RMS of WCS solution for each detector. | Robust average of residuals from WCS solution for each detector. Measure of integrity of WCS solution. |
| QC.WCS_SCALE [deg/pixel] Measured WCS plate scale per detector. | Measure of the average on-sky pixel scale of detector after correcting using current polynomial distortion model |
| QC.WCS_SHEAR [deg] Power of cross-terms in WCS solution [deg]. | Measure of WCS shear after normalizing by plate scale and rotation, expressed as an equivalent distortion angle. Gives a simple measure of distortion problems in WCS solution. |
| QC.ZPT_2MASS [mag] $1^{st}$-pass photometric zeropoint. | The magnitude of a star that gives 1 detected ADU $s^{-1}$ (or $e^{-}$ $s^{-1}$) for each detector, derived using 2MASS comparison stars for every science observation. This is a first pass zero-point to monitor gross changes in throughput. Extinction will vary over a night, but detector to detector variations are an indication of a fault. |
| QC.ZPT_STDS [mag] $2^{nd}$-pass photometric zeropoint. | The magnitude of a star that gives 1 detected ADU $s^{-1}$ (or $e^{-}$ $s^{-1}$) for each detector, derived from observations of VISTA standard star fields. Combined with the trend in long-term system zero-point properties, the ensemble "average" zero-point directly monitors extinction variations (faults/mods in the system notwithstanding) The photometric zeropoints will undoubtedly vary (slowly) over time as a result of the cleaning of optical surfaces etc. |
| QC.ZPT_STDS_CAT Standard catalog for photometric zeropoint. | This is a label for the standard star catalog used to calculate the photometric zeropoint. |

# A VISTA/VIRCAM Template Reference

## A.1 Introduction to the Phase 2 preparation for public surveys

All scientific and calibration observations with ESO instruments are prepared as observing blocks (OBs) with the Phase 2 Proposal Preparation (P2PP) tool. The scheduling of these OBs is then done on-site with the broker of observing blocks (BOB) tool, and the P2PP in visitor mode or with the Observation Tool (OT) during the Service Mode (SM) observations.

Observing blocks contain the target information, a small number of user selected templates, constraints sets and the scheduling (timing) information. The parameters of the templates define the configuration and setup to be used for the respective observations. Some parameters are selectable by users, others are “hidden” from the users to compact and to simplify the templates. The hidden parameters cannot be changed by the users but only by the telescope and instrument operators. The templates are reviewed, usually at change of observing periods, and the list of their parameters might undergo modifications. Therefore, the users should use the latest version of this Manual for the preparation of their observations.

For the ESO survey telescopes (VISTA and VST) a survey area definition tool (SADT) was developed to allow the preparation of large number of similar or identical OBs, necessary for covering large survey areas with “tiles” (a mosaic of six “pawprints” offset that covers twice, nearly uniformly the otherwise sparsely populated VIRCAM filed of view; see Sec. 6.3). The SADT also selects auto guider and wave front sensor stars from astronomical catalogs. The result of the survey area definition is written at the end into an xml-format file, to be imported later into P2PP. The user is required to prepare only one initial OB (or a few, if the survey is not entirely uniform), and the P2PP will clone duplicate OBs with the same parameter sets for every tile of the survey. The SADT is described in detail in a separate user manual.

Both P2PP and OT were heavily modified with respect to the previous versions to handle the large number of public survey OBs. The most prominent modification is the new functionality to group the OBs in scheduling containers (Sec. 6.4). For the first year there will be three scheduling containers: Concatenations, Time Links and Groups.

The relatively straightforward design of VISTA/VIRCAM requires only a small number of observation

Table 9: VISTA/VIRCAM templates.

| Template Name | Functionality |
|---|---|
| VIRCAM_img_acq | preset, instrument setup and acquisition of guide stars |
| VIRCAM_img_obs_tile1 | take a jitter and microstep sequence on one pawprint |
| VIRCAM_img_obs_tile3 | take a jitter and microstep sequence on three vertical pawprint |
| VIRCAM_img_obs_tile6 | take a jitter and microstep sequence on a full set of 6 pawprints |
| VIRCAM_img_cal_illumination | take an illumination correction |
| VIRCAM_img_cal_std | take a standard star observation |
| VIRCAM_img_obs_paw | take a jitter and microstep sequence on one pawprint without selecting guide stars |
| VIRCAM_img_obs_offsets | make a sequence of exposures at a user-defined set of telescope offsets. |

templates (Table 9): one acquisition template and three observations templates. Some additional templates that can operate without input files from the SADT might be implemented in the future. Most surveys are likely to use only two templates: VIRCAM_img_acq and VIRCAM_img_obs_tile6. The calibration observations like twilight flats, darks, and standard star observations, as well as the maintenance templates are not prepared by the users. They are not described in this user manual and event though some are included in the publically delivered instrument package for reasons of completeness or because of sharing common libraries, they are not to be used by the survey teams.

The observing strategy and the optimization of VISTA observations are discused in Sec. 6.5. Next, we will describe the VISTA/VIRCAM templates.

## A.2 The acquisition template — VIRCAM_img_acq

This template acquires a science target. It sets the instrument into IMAGING mode (which is a hidden parameter) and selects a science filter (if one has been specified). It also points the telescope to a new target (using a "preset"). The pointing center is the rotator center unless specified otherwise in the optional (X,Y) parameters. The default field of view orientation points the Y axis to the North and X axis to the West. Any position angle specified refers to the position angle at the pointing center (i.e. the meridian line of the TEL.TARG.ALPHA should intersect the column of pixels at TEL.TARG.X at angle TEL.ROT.OFFANGLE). If autoguiding and active optics correction are required to be set by the acquisition template (TEL.AG.START='T' and TEL.AO.START='T') one guide star and two AO stars are to be specified, if not read from on-line catalogs (see below). Some parameters (TEL.GS1–5.ALPHA, TEL.GS1–5.DELTA, and TEL.GS1–5.MAG) appear five times in the template for the five guide stars, respectively. A brief description of the main parameters is given bellow:

**– TEL.AG.CONFIRM, TEL.AO.CONFIRM :** select if the operator will be asked to confirm starting the autoguiding and low order wave front sensing, based on his evaluation of the AG and AO performance.

**– TEL.AG.GUIDESTAR, TEL.AO.AOSTARA, TEL.AO.AOSTARB :** select the source of guide and wave front sensor stars; the options are the OB ("SETUPFILE"), an on-line catalog ("CATALOG") or no stars shall be used ("NONE"). This should be left on "SETUPFILE" for the time being.

**– TEL.AG.START, TEL.AO.START :** select if the autoguiding and low order wave front sensing shall be started or not. This should be set to "F" for public surveys prepared with SADT where the guide and WFS stars are provided for all pawprints in the "tile"-templates.

**– TEL.TARG.X, TEL.TARG.X :** set an initial offset on the focal plane (in mm); leave to zeros for normal survey observations, non-zero values are fro technical observations only.

**– TEL.AO.PRIORITY :** allows the users to specify if the low order active optics corrections have "HIGH", "NORMAL" or "LOW" priority with respect to the science observations. At "LOW" priority the acquisition sequence would not wait for the active optics before starting the science observation sequence. The parameter should be left in "NORMAL" for normal survey observations.

The sequence of the target/field acquisition is summarized below. To save time, the instrument will be set up in parallel to the telescope preset. With the default parameter setting there will be no step that require manual interaction.

```
If pointing origin is not (0,0) then
   Adjust telescope coordinates to bring target to pointing origin.
End if
Set instrument mode to IMAGING.
   If science filter has been specified
      Select science filter.
   End if
```

Table 10: VISTA/VIRCAM acquisition template parameters.

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| TEL.TARG.ALPHA | coord | 000000..240000 | – | RA | Alpha for the target in HHMMSS.TTT |
| TEL.TARG.DELTA | coord | −900000..900000 | – | DE | Delta for the target in DDMMSS.TTT |
| TEL.TARG.EQUINOX | keyword | −2000 – 3000 | 2000 | Equinox | Equinox expressed as year |
| TEL.ROT.ENABLED | boolean | T F | T | Enable rotator preset? | If T, rotator preset is enabled (HIDDEN!) |
| TEL.ROT.OFFANGLE | number | −180.0..180.0 | 0.0 | Camera sky position angle | Camera sky position angle as +-DDD.TTT |
| TEL.TARG.ADDVELALPHA | number | −15..15 | 0.0 | Differential tracking in RA | Alpha additional tracking velocity in arcseconds/s |
| TEL.TARG.ADDVELDELTA | number | −15..15 | 0.0 | Differential tracking in DEC | Delta additional tracking velocity in arcseconds/s |
| TEL.TARG.PMA | number | −500..500 | 0.0 | Proper motion in RA | Proper Motion Alpha in arcseconds/year |
| TEL.TARG.PMD | number | −500..500 | 0.0 | Proper motion in DEC | Proper Motion Delta in arcseconds/year |
| TEL.TARG.EPOCH | keyword | 1950/2000 | 2000 | Epoch | Epoch expressed as year. Only 1950 or 2000 are valid values |
| TEL.TARG.EPOCHSYSTEM | keyword | J/B | J | Epoch system (default J=Julian) | Epoch system expressed as a |
| TEL.TARG.X | number | −500.0..500.0 | 0.0 | X coord of pointing | Pointing origin X in focal plane (mm). |
| TEL.TARG.Y | number | −500.0..500.0 | 0.0 | Y coord of pointing | Pointing origin Y in focal plane (mm). |
| TEL.AG.CONFIRM | boolean | T F | F | Confirm guide star? | If T, then request operator confirmation, otherwise not. |
| TEL.AG.GUIDESTAR | keyword | NONE SETUPFILE CATALOGUE | SETUPFILE | Select guide star from? | Where will guide star be selected (NONE, SETUPFILE or CATALOGUE)? |
| TEL.AG.START | boolean | T F | T | Enable autoguiding | If T, then autoguiding is enabled, otherwise not. |
| TEL.GS1.ALPHA | coord | 000000..240000 | 0.0 | RA of guide star 1 | Guide Star 1 alpha as HHMMSS.TTT |
| TEL.GS1.DELTA | coord | −900000..900000 | 0.0 | DEC of guide star 1 | Guide Star 1 delta as +-DDMMSS.TTT |
| TEL.GS1.MAG | number | 0..25 | 25.0 | Magnitude of guide star 1 | Guide Star 1 magnitude. |
| ... identical entries for GS2, GS3, and GS4 ... | | | | | |
| TEL.GS5.ALPHA | coord | 000000..240000 | 0.0 | RA of guide star 5 | Guide Star 5 alpha as HHMMSS.TTT |
| TEL.GS5.DELTA | coord | −900000..900000 | 0.0 | DEC of guide star 5 | Guide Star 5 delta as +-DDMMSS.TTT |
| TEL.GS5.MAG | number | 0..25 | 25.0 | Magnitude of guide star 5 | Guide Star 5 magnitude. |
| TEL.AO.AOSTARA | keyword | NONE SETUPFILE CATALOGUE | SETUPFILE | Select aO star A from?” | Where will aO star A be selected (NONE, SETUPFILE or CATALOGUE)? |
| TEL.AO.AOSTARB | keyword | NONE SETUPFILE CATALOGUE | SETUPFILE | Select aO star B from?” | Where will aO star B be selected (NONE, SETUPFILE or CATALOGUE)? |
| TEL.AO.CONFIRM | boolean | T F | F | Confirm active optics? | If T, then request operator confirmation, otherwise not. |

Table 10: VISTA/VIRCAM acquisition template parameters (continued).

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| TEL.AO.PRIORITY | keyword | LOW NORMAL HIGH | NORMAL | Active optics priority | LOW=never wait, NORMAL=sometimes wait, HIGH=always wait. |
| TEL.AO.START | boolean | T F | T | Enable active optics | If T, then active optics is enabled, otherwise not. |
| TEL.AOSA1.ALPHA | coord | 000000..240000 | 0.0 | RA of LOWFS PY star 1 | aO A (PY) 1 Star alpha as HHMMSS.TTT |
| TEL.AOSA1.DELTA | coord | −900000..900000 | 0.0 | DEC of LOWFS PY star 1 | aO A (PY) 1 Star delta as +-DDMMSS.TTT |
| TEL.AOSA1.MAG | number | 0..25 | 25.0 | Magnitude of LOWFS PY star 1 | aO A (PY) 1 Star magnitude. |
| ... identical entries for AOSA2, AOSA3, and AOSA4 ... | | | | | |
| TEL.AOSA5.ALPHA | coord | 000000..240000 | 0.0 | RA of LOWFS PY star 5 | aO A (PY) 5 Star alpha as HHMMSS.TTT |
| TEL.AOSA5.DELTA | coord | −900000..900000 | 0.0 | DEC of LOWFS PY star 5 | aO A (PY) 5 Star delta as +-DDMMSS.TTT |
| TEL.AOSA5.MAG | number | 0..25 | 25.0 | Magnitude of LOWFS PY star 5 | aO A (PY) 5 Star magnitude. |
| TEL.AOSB1.ALPHA | coord | 000000..240000 | 0.0 | RA of LOWFS NY star 1 | aO B (NY) 1 Star alpha as HHMMSS.TTT |
| TEL.AOSB1.DELTA | coord | −900000..900000 | 0.0 | DEC of LOWFS NY star 1 | aO B (NY) 1 Star delta as +-DDMMSS.TTT |
| TEL.AOSB1.MAG | number | 0..25 | 25.0 | Magnitude of LOWFS NY star 1 | aO B (NY) 1 Star magnitude. |
| ... identical entries for AOSB2, AOSB3, and AOSB4 ... | | | | | |
| TEL.AOSB5.ALPHA | coord | 000000..240000 | 0.0 | RA of LOWFS NY star 5 | aO B (NY) 5 Star alpha as HHMMSS.TTT |
| TEL.AOSB5.DELTA | coord | −900000..900000 | 0.0 | DEC of LOWFS NY star 5 | aO B (NY) 5 Star delta as +-DDMMSS.TTT |
| TEL.AOSB5.MAG | number | 0..25 | 25.0 | Magnitude of LOWFS NY star 5 | aO B (NY) 5 Star magnitude. |
| TEL.TWEAK | boolean | T F | F | Enable manual tweaking of position | If T, then template pauses while the telescope is tweaked. (HIDDEN!) |
| INS.FILTER.NAME | keyword | ISF FILTERS | | Filter name | Name of the filter element to place in the beam (checks switches). |
| INS.MODE | keyword | ISF MODES | NODEFAULT | Instrument Mode | Instrument Mode (NOTA BENE: set to IMAGING in the template |

```
Preset telescope to target.
If science filter has been specified
   Adjust telescope focus for science filter.
End if
If autoguiding is enabled then
   If AG.CONFIRM is TRUE then
      Prompt operator to confirm autoguiding.
   End if
   Wait for autoguiding to start
End if
If active optics are enabled and AO.PRIORITY is > 0 then
   Wait for active optics to start
End if
```

## A.3 The science observation templates – VIRCAM_img_obs_tile<N>

The science templates generate contiguous tiles, using a selection of pawprints, jitter and microstep telescope movements, implementing the nesting strategies described in Sec.6.5. They also set up the instrument filter wheel and configure the detector controller with the required readout and exposure time parameters. There are three template versions depending on the number of pawprints in the tile pattern: VIRCAM_img_obs_tile1, VIRCAM_img_obs_tile3, and VIRCAM_img_obs_tile6. The template parameters are listed in Table 11. Similar to the acquisition template: A large fraction of the parameters are either filled in by P2PP while importing the survey definition or are meant to be left unchanged in almost all cases.

Each time a new pawprint is selected, the TCS is provided with a new guide star and a new pair of AO stars, read from the PAF files provided with the template, or from a catalog. The pawprint, jitter and microstep patterns are made using the camera position angle specified in the acquisition template VIRCAM_img_acq, unless a new position angle is specified in the science template.

If the science template observes in multiple filters specified in a list, it may be necessary to use different DITs and NDITs for each of them (because the filters have different transmissions, and the targets may have different colors). It is possible to do this by specifying the DET.DIT and DET.NDIT parameters as lists. The lists must have exactly the same length as the list of science filters but if DET.DIT and DET.NDIT are given as single values, these exposure parameters will be applied to all filters. For example:

| | |
|---|---|
| DET.DIT | "1.0" |
| DET.NDIT | "12" |
| INS.FILTER.NAME | "H J $K_S$" |

will obtain exposures in H, J and $K_S$ filters, built as 12 co-adds (not averages!) of 1.0 sec, and

| | |
|---|---|
| DET.DIT | "2.0 3.0 1.0" |
| DET.NDIT | "6 4 12" |
| INS.FILTER.NAME | "H J $K_S$" |

the exposures in H, J and $K_S$ filters will be built as 6 co-adds of 2.0 sec, 4 co-adds of 3.0 sec, 12 co-adds of 1.0 sec, respectively.

The SEQ.TILE.ID keyword can be left at the default value for VIRCAM_img_obs_tile1 and VIRCAM_img_obs_tile6 templates. In case of the VIRCAM_img_obs_tile3 template there may be reasons (like to keep the execution time of the OB below the limit of 1.5 hrs) to cover the tile with two OBs of which one is prepared with the Tile3nx, and the other with the Tile3px pattern (Table 12).

The SEQ.USTEP.ID keyword can be set to: Single (default, 1 exposure), Ustep2 (2 exposures offset by half pixels in x and y), and Ustep2x2 (4 exposures taken with half pixel offsets in a squared pat-

Table 11: VISTA/VIRCAM science template parameters.

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| DET1.DIT | numlist | 0.0..3600.0 | – | (List of) integration time(s) | Single integration time in seconds or list of times for each filter |
| DET1.NDIT | intlist | ISF IR.NDIT.RANGE | – | (List of) number of integrations | Single NDIT or list of NDITs for each filter |
| DET1.NCORRS.NAME | keyword | ISF NCORRS_RANGE | ISF NCORRS_DEFAULT | Readout mode | Detector readout mode (as defined in detector config file). (HIDDEN!) |
| SEQ.DPR.CATG | keyword | TEST TECHNICAL ACQUISITION CALIB SCIENCE | SCIENCE | DPR category | Data product category (as defined by DICB); NOTA BENE: the value SCIENCE is hardcoded in the template |
| SEQ.DPR.TECH | keyword | IMAGE IMAGE,JITTER | IMAGE | Data product technique (as defined by DICB) | Data type classification inforation; NOTA BENE: the value IMAGE is hardcoded in the template |
| SEQ.DPR.TYPE | keyword | BIAS DARK DARK,DARKCURRENT DARK,PERSISTENCE DARK,LINEARITY DARK,GAIN FLAT FLAT,LAMP FLAT,LAMP,LINEARITY FLAT,LAMP,GAIN FLAT,TWILIGHT OBJECT OBJECT,PSF-CALIBRATOR OBJECT,PERSISTENCE OBJECT,CROSSTALK OBJECT,EXTENDED STD,ILLUMINATION STD,FLUX | OBJECT | DPR type | Data product type (as defined by DICB); NOTA BENE: the value OBJECT is hardcoded in the template |
| SEQ.JITTER.ID | keyword | ISF JITTER_RANGE | – | Name of jitter pattern | Name of jitter pattern as listed in instrument package |
| SEQ.JITTER.MAX | number | 0.0..150.0 | 20.0 | Maximum size of jitter | Maximum size of a randomized jitter (in arcseconds) |

Table 11: VISTA/VIRCAM science template parameters (continued).

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| SEQ.JITTER.NJITTER | number | 1..100 | 5 | Number of jitters | Number of points in a randomized jitter |
| SEQ.JITTER.SCALE | number | 0.0..10.0 | 1.0 | Jitter scale multiplier | Multiplier for each jitter step (1=normal) |
| SEQ.JITTER.TOARCSEC | number | 0.0..1000.0 | 1.0 | Arcseconds conversion factor | Offsets are multiplied by this to get arcseconds (HIDDEN!) |
| SEQ.NESTING | keyword | FPJME PFJME FJPME | FPJME | Nesting | Filter Pawprint Jitter Microstep Exposure nesting (FPJME PFJME FJPME) |
| SEQ.NEXPO | integer | 1..500 | 1 | Number of repeats at each position | Number of exposures at each pointing within sequence (1..500); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.REF.FILE1 | paramfile | – | – | Guide star setup file for pawprint 1 | A TCS setup file defining new AG and aO stars for each pawprint |
| SEQ.REF.FILE2 | paramfile | – | – | Guide star setup file for pawprint 2 | A TCS setup file defining new AG and aO stars for each pawprint (only for VIRCAM_img_obs_tile3 and VIRCAM_img_obs_tile6) |
| SEQ.REF.FILE3 | paramfile | – | – | Guide star setup file for pawprint 3 | A TCS setup file defining new AG and aO stars for each pawprint (only for VIRCAM_img_obs_tile3 and VIRCAM_img_obs_tile6) |
| SEQ.REF.FILE4 | paramfile | – | – | Guide star setup file for pawprint 4 | A TCS setup file defining new AG and aO stars for each pawprint (only for VIRCAM_img_obs_tile6) |
| SEQ.REF.FILE5 | paramfile | – | – | Guide star setup file for pawprint 5 | A TCS setup file defining new AG and aO stars for each pawprint (only for VIRCAM_img_obs_tile6) |
| SEQ.REF.FILE6 | paramfile | – | – | Guide star setup file for pawprint 6 | A TCS setup file defining new AG and aO stars for each pawprint (only for VIRCAM_img_obs_tile6) |
| SEQ.REF.MAXFILES | integer | – | | Number of pawprints/guide star setup files | The number of pre-defined SEQ.REF.FILE keywords. Do not change (HIDDEN!); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.TILE.FROMPAW | integer | | | Start tile from pawprint | Do not change this parameter for TILE1. (HIDDEN!); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.TILE.ID | keyword | ISF TILE_RANGE1 | ISF TILE_DEFAULT1 | Name of tile pattern | Name of tile pattern as listed in instrument package |

Table 11: VISTA/VIRCAM science template parameters (continued).

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| SEQ.TILE.SCALE | number | 0.0..10.0 | 1.0 | Scale factor | Multiplication factor for each tile step (1=normal overlap) |
| SEQ.TILE.TOARCSEC | number | 0.0..1000.0 | ISF CCD.SIZE | Arcseconds conversion factor | Offsets are multiplied by this to get arcseconds. (HIDDEN!) |
| SEQ.USTEP.ID | keyword | ISF USTEP_RANGE | ISF USTEP_DEFAULT | Name of microstep pattern | Name of microstep pattern |
| SEQ.USTEP.SCALE | number | 0.0..4.0 | 1.0 | Microstep scale multiplier | Multiplier of each microstep step (1=normal); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.USTEP.TOARCSEC | number | 0.0..1000.0 | ISF PIXEL.SIZE | Arcseconds conversion factor | Offsets are multiplied by this to get arcseconds. (HIDDEN!) |
| INS.FILTER.NAME | keywordlist | ISF FILTERS_SCI | – | List of science filters | List of science filters to be sequenced |
| OCS.EXTENDED | boolean | T F | F | Is object extended? | T if object will require an offset sky calibration, otherwise F |
| OCS.RECIPE | keywordlist | DEFAULT OFFSETSKY EXTENDED NEAREST DRIZZLE INTERPOLATE CUBICSPLINE LANCZOS3 CUBICKEYS | DEFAULT | Pipeline recipe | Keywords for data reduction recipe for ESO/VLT pipeline |

Table 12: Combination of different offset patterns.

| | |
|---|---|
| **VIRCAM_Tile3nx** | 3 step nx (negative x) pattern |
| SEQ.TILE.OFFSETX | −0.475 -0.475 -0.475 |
| SEQ.TILE.OFFSETY | −0.475 0.0 0.475 |
| **VIRCAM_Tile3px** | 3 step px (positive x) pattern |
| SEQ.TILE.OFFSETX | 0.475 0.475 0.475 |
| SEQ.TILE.OFFSETY | −0.475 0.0 0.475 |
| **VIRCAM_Tile6u** | 6 step u pattern (default forVIRCAM_img_obs_tile6) |
| SEQ.TILE.OFFSETX | −0.475 -0.475 -0.475 0.475 0.475 0.475 |
| SEQ.TILE.OFFSETY | 0.475 0.0 -0.475 -0.475 0.0 0.475 |

tern). In summary, the sequence would take for every filter of the list, at every of typically 6 pawprints of a tile, at every jitter position either 1, 2 or 4 exposures offset by half pixel size microsteps.

A brief description of same template parameters:

**– DPR.CATG, DPR.TYPE, DPR.TECH :** parameters used to classify the data products created by the observing template. The content of these keyword is saved into the fits file header, and it is used to trigger the respective data reduction pipeline recipe.

**– OCS.EXTENDED, OCS.RECIPE :** this parameter is used to specify a data reduction recipe; should be left at the default value.

**– DET.NCORRS.NAME :** detector readout mode; currently only “Double” (standing for Double Corelation) is allowed.

**– SEQ.JITTER.SCALE, SEQ.TILE.SCALE, SEQ.USTEP.SCALE :** define the scale factors to increase the dimensionless offset (see below) read from the setup files.

**– SEQ.JITTER.TOARCSEC, SEQ.TILE.TOARCSEC, SEQ.USTEP.TOARCSEC :** conversion factor to turn the offsets into arcseconds.

**– SEQ.JITTER.ID, SEQ.TILE.ID, SEQ.USTEP.ID :** selects offset patterns for the jitter, tile and microstep sequences, respectively. Unlike for other ESO instruments, the VISTA offsets are absolute with respect to the initial position at the start of the observing sequence. The user has to select one of the predefine jitter patterns (Table 13; they may be modified, please consult the latest version of this manual or the VISTA web pages for the most recent updates).

The science observation sequence can be summarized in the following program listing, in case of the default “nesting”:

```
If SEQ.NESTING is FPJME then
   For each science filter
      Select science filter
      Determine telescope focus for science filter.
      For each pawprint
         If SEQ.REF.FILE(pawprint) is not a blank or null string then
            If SEQ.REF.FILE(pawprint) file exists then
               Define new guide star setup parameters from
               SEQ.REF.FILE(pawprint).
            Else
               Issue warning and define new guide star setup
               parameters to select stars on the fly from
               online catalogue.
            Endif
```

Table 13: Offset patterns.

| | |
|---|---|
| **VIRCAM_Jitter2d** | 2 step / down pattern |
| SEQ.JITTER.OFFSETX | 10.0 -10.0 |
| SEQ.JITTER.OFFSETY | 10.0 -10.0 |
| **VIRCAM_Jitter2u** | 2 step / up pattern |
| SEQ.JITTER.OFFSETX | -10.0 10.0 |
| SEQ.JITTER.OFFSETY | -10.0 10.0 |
| **VIRCAM_Jitter2x2** | 2x2 pattern |
| SEQ.JITTER.OFFSETX | -10.0 -10.0 10.0 10.0 |
| SEQ.JITTER.OFFSETY | -10.0 10.0 -10.0 10.0 |
| **VIRCAM_Jitter3d** | 3 step / down pattern |
| SEQ.JITTER.OFFSETX | 10.0 0.0 -10.0 |
| SEQ.JITTER.OFFSETY | 10.0 0.0 -10.0 |
| **VIRCAM_Jitter3u** | 3 step / up pattern |
| SEQ.JITTER.OFFSETX | -10.0 0.0 10.0 |
| SEQ.JITTER.OFFSETY | -10.0 0.0 10.0 |
| **VIRCAM_Jitter3x3** | 3x3 + pattern |
| SEQ.JITTER.OFFSETX | 0.0 -10.0 -10.0 10.0 10.0 -10.0 0.0 10.0 0.0 |
| SEQ.JITTER.OFFSETY | 0.0 -10.0 10.0 10.0 -10.0 0.0 10.0 0.0 -10.0 |
| **VIRCAM_Jitter5p** | 5 step + pattern |
| SEQ.JITTER.OFFSETX | 0.0 -10.0 0.0 10.0 0.0 |
| SEQ.JITTER.OFFSETY | 0.0 0.0 10.0 0.0 -10.0 |
| **VIRCAM_Jitter5x** | 5 step X pattern |
| SEQ.JITTER.OFFSETX | 0.0 -10.0 -10.0 10.0 -10.0 |
| SEQ.JITTER.OFFSETY | 0.0 -10.0 10.0 10.0 -10.0 |
| **VIRCAM_Jitter5x5** | 5x5 spiral pattern |
| SEQ.JITTER.OFFSETX | 0 -10 -10 0 10 10 10 0 -10 -20 -20 -20 -20 -10 0 10 20 20 20 20 20 10 0 -10 -20 |
| SEQ.JITTER.OFFSETY | 0 0 -10 10 10 0 -10 -10 -10 -10 0 10 20 20 20 20 20 10 0 -10 -20 -20 -20 -20 -20 |

```
         Else
            (Keep previously defined stars).
         Endif
         For each jitter offset
            For each microstep offset.
               Convert (X,Y,ROT) offset into (ALPA,DELTA,ROT) offset
               Offset telescope to pawprint, jitter and microstep offset
               If new guide stars are available then
                  If TEL.AG.START is TRUE then
                     If AG.CONFIRM is TRUE then
                        Prompt operator to confirm autoguiding.
                     End if
                     Wait for autoguiding to start
                  End if
                  If TEL.AO.START is TRUE and AO.PRIORITY > 0 then
                     Wait for active optics to start
                  End if
               Endif
               Get WCS information from TCS.
               Calculate dwell time (NEXPO * DIT * NDIT) and inform TCS.
               For each exposure
                  Define header keywords:
                     TILE_ID, TILE_I, TILENUM
                     NJITTER,JITTRNUM,JITTR_ID,JITTER_I,JITTER_X,JITTER_Y,
                     NUSTEP, USTEPNUM, USTEP_ID, USTEP_I, USTEP_X, USTEP_Y
                  Set WCS parameters.
                  Make exposure
               Next exposure
            Next microstep
         Next jitter
      Next pawprint
   Next science filter
Else if SEQ.NESTING is PFJME then
   ...
   ...
Else if SEQ.NESTING is FJPME then
   ...
   ...
End if
```

**Number of exposures taken with a science observation template :** for N filters in the list, 6 pawprints taken within the tile6 template, 5 jitter positions of the jitter5x pattern, and 2 microjitter exposures, one would obtain $N\times6\times5\times2=N\times60$ exposures (written on the disk in 60 different fits files). Each exposure is the sum of NDIT individual detector integrations of DIT seconds.

## A.4 The calibration template – VIRCAM_img_cal_illumination and VIRCAM_img_cal_std

The parameters of the illumination correction template VIRCAM_img_cal_illumination and the standard star template VIRCAM_img_cal_std are listed in Tables 14 and 15.

Table 14: VISTA/VIRCAM illumination correction template parameters.

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| DET1.DIT | numlist | 0.0..3600.0 | 10.0 | (List of) integration time(s) | Single integration time in seconds or list of times for each filter |
| DET1.NDIT | intlist | ISF IR.NDIT.RANGE | 1 | (List of) number of integrations | Single NDIT or list of NDITs for each filter |
| DET1.NCORRS.NAME | keyword | ISF NCORRS_RANGE | ISF NCORRS_DEFAULT | Readout mode | Detector readout mode (as defined in detector config file). (HIDDEN!) |
| SEQ.DPR.CATG | keyword | TEST TECHNICAL ACQUISITION CALIB SCIENCE | SCIENCE | DPR category | Data product category (as defined by DICB); NOTA BENE: the value CALIB is hardcoded in the template |
| SEQ.DPR.TECH | keyword | IMAGE IMAGE,JITTER | IMAGE | Data product technique (as defined by DICB) | Data type classification inforation; NOTA BENE: the value IMAGE is hardcoded in the template |
| SEQ.DPR.TYPE | keyword | BIAS DARK DARK,DARKCURRENT DARK,PERSISTENCE DARK,LINEARITY DARK,GAIN FLAT FLAT,LAMP FLAT,LAMP,LINEARITY FLAT,LAMP,GAIN FLAT,TWILIGHT OBJECT OBJECT,PSF-CALIBRATOR OBJECT,PERSISTENCE OBJECT,CROSSTALK OBJECT,EXTENDED STD,ILLUMINATION STD,FLUX | OBJECT | DPR type | Data product type (as defined by DICB); NOTA BENE: the value STD,ILLUMINATION is hardcoded in the template |
| SEQ.NEXPO | integer | 1..500 | 1 | Number of repeats at each position | Number of exposures at each pointing within sequence (1..500); NOTA BENE: the value 1 is hardcoded in the template |

Table 14: VISTA/VIRCAM illumination correction template parameters (continued).

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| SEQ.OFFSETALPHA | numlist | −6000.0..6000.0 | ISF CCD.POSITIONS.X | List of tel. RA offsets (arcsec) | VISTA uses absolute offsets from the original target coordinates |
| SEQ.OFFSETDELTA | numlist | −6000.0..6000.0 | ISF CCD.POSITIONS.Y | List of tel. DEL offsets (arcsec) | VISTA uses absolute offsets from the original target coordinates |
| SEQ.OFFSETROT | numlist | −180.0..180.0 | 0.0 | List of tel. rotator offsets (degrees) | VISTA uses absolute offsets from the original target coordinates |
| SEQ.REF.FILE1 | string | – | NONE | Guide star setup file for offset 1 | A TCS ref setup file defining new AG and aO stars for each offset (HIDDEN!) |
| ... identical entries for guiding stars 2,,3, 4, ... to 16 ... | | | | | |
| SEQ.REF.MAXFILES | integer | – | – | Maximum number of guide star setup files | The number of pre-defined SEQ.REF.FILE keywords. Do not change. (HIDDEN!) NOTA BENE: the value 16 is hardcoded in the template |
| INS.FILTER.NAME | keywordlist | ISF FILTERS_SCI | ISF FILTERS_SCI | List of science filters | List of science filters to be sequenced |
| OCS.EXTENDED | boolean | T F | F | Is object extended? | T if object will require an offset sky calibration, otherwise F |
| OCS.RECIPE | keywordlist | DEFAULT OFFSETSKY EXTENDED NEAREST DRIZZLE INTERPOLATE CUBICSPLINE LANCZOS3 CUBICKEYS | DEFAULT | Pipeline recipe | Keywords for data reduction recipe for ESO/VLT pipeline |

Table 15: VISTA/VIRCAM photometric standard star template parameters.

| Keyword | Type | Range | Default | P2PP Label | Description |
|---|---|---|---|---|---|
| DET1.DIT | numlist | 0.0..3600.0 | – | (List of) integration time(s) | Single integration time in seconds or list of times for each filter |
| DET1.NDIT | intlist | ISF IR.NDIT.RANGE | – | (List of) number of integrations | Single NDIT or list of NDITs for each filter |
| DET1.NCORRS.NAME | keyword | ISF NCORRS_RANGE | ISF NCORRS_DEFAULT | Readout mode | Detector readout mode (as defined in detector config file). (HIDDEN!) |
| SEQ.DPR.CATG | keyword | TEST TECHNICAL ACQUISITION CALIB SCIENCE | SCIENCE | DPR category | Data product category (as defined by DICB); NOTA BENE: the value CALIB is hardcoded in the template |
| SEQ.DPR.TECH | keyword | IMAGE IMAGE,JITTER | IMAGE | Data product technique (as defined by DICB) | Data type classification inforation; NOTA BENE: the value IMAGE is hardcoded in the template |
| SEQ.DPR.TYPE | keyword | BIAS DARK DARK,DARKCURRENT DARK,PERSISTENCE DARK,LINEARITY DARK,GAIN FLAT FLAT,LAMP FLAT,LAMP,LINEARITY FLAT,LAMP,GAIN FLAT,TWILIGHT OBJECT OBJECT,PSF-CALIBRATOR OBJECT,PERSISTENCE OBJECT,CROSSTALK OBJECT,EXTENDED STD,ILLUMINATION STD,FLUX | OBJECT | DPR type | Data product type (as defined by DICB); NOTA BENE: the value STD,FLUX is hardcoded in the template |
| SEQ.JITTER.ID | keyword | ISF JITTER_RANGE | – | Name of jitter pattern | Name of jitter pattern as listed in instrument package |

Table 15: VISTA/VIRCAM photometric standard star template parameters (continued).

| Keyword | Type | Range | Default | P2PP Label | Description |
| --- | --- | --- | --- | --- | --- |
| SEQ.JITTER.MAX | number | 0.0..150.0 | 20.0 | Maximum size of jitter | Maximum size of a randomized jitter (in arcseconds) |
| SEQ.JITTER.NJITTER | number | 1..100 | 5 | Number of jitters | Number of points in a randomized jitter |
| SEQ.JITTER.SCALE | number | 0.0..10.0 | 1.0 | Jitter scale multiplier | Multiplier for each jitter step (1=normal) |
| SEQ.JITTER.TOARCSEC | number | 0.0..1000.0 | 1.0 | Arcseconds conversion factor | Offsets are multiplied by this to get arcseconds (HIDDEN!) |
| SEQ.NESTING | keyword | FPJME PFJME FJPME | FPJME | Nesting | Filter Pawprint Jitter Microstep Exposure nesting (FPJME PFJME FJPME) |
| SEQ.NEXPO | integer | 1..500 | 1 | Number of repeats at each position | Number of exposures at each pointing within sequence (1..500); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.USTEP.ID | keyword | ISF USTEP_RANGE | ISF USTEP_DEFAULT | Name of microstep pattern | Name of microstep pattern |
| SEQ.USTEP.SCALE | number | 0.0..4.0 | 1.0 | Microstep scale multiplier | Multiplier of each microstep step (1=normal); NOTA BENE: the value 1 is hardcoded in the template |
| SEQ.USTEP.TOARCSEC | number | 0.0..1000.0 | ISF PIXEL.SIZE | Arcseconds conversion factor | Offsets are multiplied by this to get arcseconds. (HIDDEN!) |
| INS.FILTER.NAME | keywordlist | ISF FILTERS_SCI | – | List of science filters | List of science filters to be sequenced |
| OCS.EXTENDED | boolean | T F | F | Is object extended? | T if object will require an offset sky calibration, otherwise F |
| OCS.RECIPE | keywordlist | DEFAULT OFFSETSKY EXTENDED NEAREST DRIZZLE INTERPOLATE CUBICSPLINE LANCZOS3 CUBICKEYS | DEFAULT | Pipeline recipe | Keywords for data reduction recipe for ESO/VLT pipeline |

# B VISTA/VIRCAM FITS Header Description

TBA